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Campus Commuting: Barriers to Walking and Bicycling Use in a University Town

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CAMPUS COMMUTING: BARRIERS TO WALKING AND BICYCLING USE IN A UNIVERSITY TOWN

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ABSTRACT

Amongst the growing calls for environmental sustainability comes the frequently-expressed desire to increase the use of non-motorized modes of transportation for commuting. However, walking and bicycling are only viable commuting modes if people live within acceptable distances of their destination and transportation networks can safely accommodate pedestrians or bicyclists.

This research explores the potential for non-motorized modes to substitute for private-vehicle commuting for travelers to a large employment and activity center; in this case, the area surrounding Clemson University. This methodology uses a combination of stated maximum-acceptable commute times for walking and bicycling and an assessment of the suitability of the transportation network to develop walking and bicycling commute catchments from which a person could be reasonably expected to commute to a destination by walking or bicycling. Identifying commute catchments such as these then allowed analysis of deficient infrastructure that presents barriers to non-motorized commuters, as well as an examination of local land-use policy related to the commuting catchments.

The resulting methodology can be transferred to other majoy employment and activity centers to inform policy makers in terms of identifying unsuitable road segments that serve as major barriers to non-motorized forms of commuting.The results also help depict appropriate land use policies for areas that have the potential to generate a large amount of walking or bicycling traffic.

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INTRODUCTION

"Lack of parking creates problems" says the front page headline of Clemson University's college newspaper, *The Tiger*. Frustration runs high among commuters as increasing traffic congestion and a constrained supply of parking diminish the most dominant and often revered mode of commuting in the United States. Eighty-eight percent of the United States population commutes to work by private vehicle, up from the 64 percent of workers who commuted by automobile in 1960 (US Census). Transportation and urban planners are increasingly questioning the current transportation system's ability to accommodate increasing demands from private vehicle travelers. Campuses and municipalities across the nation are struggling to balance quality of life with an increasing demand for mobility.

At the same time, many researchers have even come to conclude that the automobile-accommodating transportation planning paradigm of the last 50 years may be inadequate and inappropriate in recognition of the increasing concerns of the negative externalities of automobile commuting. Academic institutions and municipalities have expressed interest in embracing principles of sustainability, which implies a need to reduce the reliance on single-occupant vehicles for commuting (Barker, 2006). For example, a policy of the 2002 Clemson University *Campus Master Plan* explicitly stated the priorities of the transportation network: "Pedestrians' needs are of the highest priority and take precedence over the demands of the motorist. All planning, design, and development should support this priority while meeting the basic needs of emergency service, maintenance services, disabled individuals, and mass transit" (*Campus Master Plan*, 2002).

For a transportation planner or policy maker, adding parking might not be the continued solution to a growing trend of automobile commuters, especially when the institution is espousing the virtues of sustainability. However, policies intended to increase the use of alternative modes of commuting to the automobile will only have an effect on transportation mode choice trends if a significant portion of the commuting population has a reasonable alternative to the automobile.

This research has developed a framework for identifying commuting catchments for non-motorized modes of transportation. These commuter catchments can predict the geographic area in which a person should be expected to have a reasonable non-motorized alternative to commuting by automobile. The process for developing these commute mode catchments is broadly applicable to not only campus environments, but for any built environment where researchers are interested in the potential for non-motorized access to major local trip attractors.

Clemson University and its surrounding area have served as a test bed for developing these commute catchments. Clemson University has been undergoing a comprehensive study to assess existing transportation patterns and plan for future transportation needs, and it is appropriate to examine why demand for automobile parking is so robust. In recent years, other universities have adopted transportation demand management policies in an attempt to reduce parking demand and encourage the use of other modes in campus environments where walking, cycling, and public transit should be well suited (Balsas, 2002). Could Clemson University and the surrounding area provide for a greater potential to use non-automobile modes of transportation for the commute to campus? This research has addressed why the most sustainable modes of commuting, walking and bicycling, have comprised a small percentage of the modes used by Clemson University students, faculty, and staff. According to 2005 survey results, 81 percent of trips by Clemson University students, faculty, and staff are made by automobile, while walking, bicycling, and public transit make up 8 percent, 4 percent, and 6 percent, respectively (Boyles, 2006).

This research has examined realized and potential nonmotorized commute catchments through the following strategies:

- analyses of the maximum acceptable commute distances and suitability of the transportation network for pedestrian and bicycle commuting in order to identify the theoretical and actual commute catchments from which campus commuters could or can walk or bicycle to campus, and
- examination of campus members' residence locations and local land use policy in relation to the identified walking and bicycling commute catchments.

The results of this research will inform decision making related to transportation, parking infrastructure, and land-use policy for any type of institution looking to explore the potential for increased non-motorized commuting or for any major trip attractor seeking to expand non-motorized access.

This report is divided into six main sections. The first section explores literature relating to the campus environment, the costs of automobile commuting, transportation demand management, mode suitability theories, and preferred and demonstrated acceptable commute times by mode. The second section lays out the specific research question and objectives of this report. The third section describes the research methodology in detail. The fourth section details the research results. The fifth section discusses the implications and recommendations for Clemson University. The report then concludes with a broader message on future applications.

LITERATURE REVIEW

THE CAMPUS ENVIRONMENT

University campuses are unique in many ways. The traditional campus often acts as a "self-contained neighborhood," with student housing, academic buildings, offices, dining, and cultural amenities in close proximity (Balsas, 2003). The relatively high density of student housing, a large employment force, and close proximity between institutional buildings typically provides for a pedestrian-oriented campus, even at universities within rural settings. Clemson University is no exception: University administration has purposely limited large parking areas to the periphery of campus to enhance the pedestrian experience. As Clemson University's *Campus Master Plan* (2002) describes, "The main campus is essentially a pedestrian campus except that parking is allowed along Core Campus roads" and "vehicular use infringes only minimally on the pedestrian."

The activity generated by a large university campus inevitably impacts the environment and surrounding community. Because many students and practically all faculty and staff live off-campus, surrounding land use patterns and infrastructure characteristics can play a significant role in determining the commuting characteristics of the off-campus population. In fact, commuting is the single largest impact a university has on the environment (Tolley, 1996). A campus itself may be pedestrian-friendly, but the surrounding neighborhood may not share the same environmental characteristics, increasing the likelihood of automobile commuting. If a university is to address the true intentions of the sustainability movement, it is not enough to focus only on the university itself.

Due to the spillover in transportation and housing demand from a university campus in to the surrounding community, coordination of land-use planning and transportation infrastructure design between a campus and surrounding area is essential to minimize the negative externalities created by a university. Unfortunately, universities and their surrounding towns often conflict over the best ways to address the impacts of university populations (Toor and Havlick, 2004). Local governments face the often opposing desires of a transient student population and a more politically influential, long-term resident population.

Universities are increasingly adopting the mantra of the sustainability movement and are well suited to do so. Broadly defined, one definition of sustainability is “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Richardson, 1999). There are three separate parts to the goal of sustainability: environmental sustainability, economic sustainability, and equitable sustainability. While many universities, including Clemson University, have made an emphasis on the environmental sustainable properties of new academic buildings, addressing the sustainability of the transportation network can have a greater impact on the larger environment. A sustainable transportation network is suggested to be one which “meet people’s needs equitably and foster a healthy environment (by) putting the automobile back into its useful place as a servant. With a shift in priorities, cars can be part of a broad, balanced system in which public transport, cycling, and walking are all viable options (Low, 1990)." In addition, innovative transportation approaches have potential to diffuse from institutes of higher education to other parts of society through their influence on the transportation habits and perceptions of the students and future leaders of society (Balsas, 2003). Sustainable transportation planning for campuses can mean "providing incentives for walking, bicycling, taking mass transit, ridesharing, discouraging the use of single-occupancy cars by passing on the full costs of parking to drivers, and linking transportation planning to land-use planning" (Balsas, 2003). As universities contemplate their desire for a sustainable, pedestrian-friendly campus, an increasingly robust demand for automobile parking is not a sign of success.

THE COSTS OF AUTOMOBILE COMMUTING

Sustainable transportation systems cannot have a large and increasing emphasis on single-occupant motor vehicles. The cost of automobile commuting is high in human, environmental, and economic terms.

Despite an improving fatality rate per mile over the last decade, motor vehicle crashes are the number one cause of death in the United States for people between the ages of 3 and 33 (NHTSA, 2005). Motor vehicle crashes were responsible for fifteen percent of all deaths in the United States in the year 2004, a total of 46,933 people killed in motor vehicle crashes (Minino et al., 2006). On average, a person died every twelve minutes in a motor vehicle crash in 2005, which in addition to being tragic, led to an estimated economic cost of $230.6 billion dollars (Minino et al., 2006).

Not only do automobiles create hazards to their users, but they are a hazard to other modes of travel that would not be nearly as dangerous without contact with automobiles. 64,000 pedestrians were injured and 4,881 were killed in traffic crashes in 2005, accounting for 11 percent of all traffic fatalities (NHTSA, 2005). Similarly, 784 cyclists were killed and an additional 45,000 were injured in traffic crashes in 2005. The high rate of fatality among pedestrians and bicyclists is not because that particular travel mode is hazardous, as the speeds obtainable via walking and cycling do not generally produce fatalities; however, contact with an automobile has proven hazardous for a person's health. The chances of survival for a pedestrian struck by a motor vehicle traveling at under twenty miles per hour are 95 percent. At thirty miles per hour, the chance of survival drops to 50 percent, while over 40 miles per hour, the chance of survival is only 15 percent (Surface Transportation Policy Project, 2003).

The deaths and injuries cited above only include those which were a direct result of a traffic crash. Automobiles have a negative health cost beyond what is caused by their weights and inertia. Automobile emissions account for 56 percent of all carbon monoxide emissions, 56 percent of nitrogen oxides, and 45 percent of volatile organic compounds (US EPA, 2003; US EPA, 2000). Increased levels of carbon monoxide have been linked to heart disease and adverse affects on the central nervous system (US EPA, 2000). Nitrogen oxides and volatile organic compounds combine to form ozone, which can cause a number of respiratory problems, such as chest pain, coughing, and throat irritation. Repeated exposure to ozone can decrease lung-capacity through lung-tissue scaring. Ozone will also greatly exasperate existing lung-related conditions, such as emphysema, bronchitis, and asthma (US EPA, 2003). Automobile commuting is also linked to the formation of airborne particular matter, which can also cause serious health conditions including respiratory and heart conditions (US EPA, 2006).

Improvements in automobile emission technology have reduced the amounts of pollutants produced per mile of vehicle travel, but the continually increasing amount of automobile travel has offset these gains. Some researchers have suggested that the easiest reductions in automobile emissions have been made, and further significant gains will require changing travel behavior (Boarnet and Crane, 2001).

Aside from the direct negative health impacts of automobile use and their emissions, health researchers have been increasingly interested in the declining use of non-motorized modes and its resulting impact on public health (Sallis et al., 2004; Frank and Engelke, 2005). The U.S. Surgeon General recommends that adults should get at least 30 minutes of moderate physical activity all days of the week. In 1997, only fifteen percent of adults obtained the recommended amount of physical activity (US Department of Health and Human Services, 2000). Utilitarian walking and bicycling is an opportunity for people to incorporate moderate physical activity into their daily routines (Frank and Engelke, 2005). Automobile commuting does not produce the same health benefits.

In addition, automobile use is energy intensive. Transportation constitutes 66.8 percent of the United States' total petroleum consumption, of which the United States imports 60 percent (Davis and Diegel, 2006). Personal transportation is estimated to use 56 percent of the total transportation energy consumption. The high degree of energy consumption for personal automobile travel has implications not only for the cost to individual users, but to society as a whole through the costs of securing and maintaining a dependable source of petroleum. On a smaller scale, the average household is expected to pay approximately $2,327 for motor vehicle fuel in 2006, a 70 percent increase from 2001 (EIA, 2005). This increase is due in part to rising petroleum prices from growing domestic and international demand, as well as to a consistent growth in vehicle miles traveled per household of 3.6 percent.

One often overlooked but important cost of automobile commuting is the actual cost of providing parking and the effects that parking has on the campus environment. Many parking users might assume that parking is generally free, an attitude reinforced by large minimum parking supply requirements imposed by local governments that typically decrease the market value of individual parking spaces for users to zero (Shoup, 2005). In a university setting, where automobile users typically do pay a fee for parking, they usually do not pay the full cost of supplying the parking space. If total costs for supplying and administrating parking on a campus exceed revenue from parking charges, universities effectively subsidize automobile use and discourage the use of more sustainable transportation modes (Tolley, 1996).

In one example from the University of Colorado, the land, construction, maintenance, and administration costs of parking was estimated at $995 per parking space per year (Toor and Havlick). The highest possible student parking rate at the University of Colorado amounted to approximately $418 per year in 2007 (UC Boulder). For comparison, bicycle parking can cost about $30 per space installed (Toor and Havlick). Over a 30-year lifecycle, bicycle users would have to be charged one dollar per academic year to recover the full cost of supplying bicycle parking. Clemson University is currently considering the construction of its first, multi-level parking structure, an expensive proposition that typically costs between $10,000 and $20,000 per space (Campus Master Plan; Toor and Havlick).

Parking is not only expensive and subsidized to a large extent, it is also land-intensive and environmentally destructive. Each parking space requires approximately 350 square feet of land, or 124 spaces per acre (Toor and Havlick). For comparison, a pedestrian requires no space for parking, and a bicycle rack holding approximately fifteen bicycles can be located in the same space as one automobile parking space. For another comparison, a typical two-person dorm room at Clemson University is approximately 150 square feet, meaning Clemson University provides more than twice the space for students' automobiles than it does for the living space of an on-campus student resident.

The large amount of space required for automobile parking greatly alters the landscape of a university. Clemson University had a supply of 13,018 parking spaces on the main campus in 2006. At 350 square feet per space, 105 acres of parking within the main campus creates a substantial amount of impervious surface that degrades local environmental quality through increased pollutants in storm water runoff.

Overwhelming evidence shows that the cost of automobile use is high in terms of human health, environmental health, and economics. Despite this evidence, the percentage of trips taken by automobile continues to climb; however, there have been increasing attempts to reduce the demand for automobile travel through transportation policy and pricing mechanisms. Transportation demand management, in particular, is a planning approach that attempts to reduce the demand for single-occupant automobile travel.

TRANSPORTATION DEMAND MANAGEMENT

Transportation demand management (TDM) attempts to curb the rise in automobile travel through "a set of actions aimed at influencing people's travel behavior in such a way that alternative mobility options are presented and/or congestion is reduced" (Meyer, 1999). TDM actions attempt to change individual travel behavior through a mix of incentives and disincentives that typically change the overall cost or quality of travel by certain modes. These strategies can include financial incentives for reducing vehicle travel, parking management, improved transit access, improved access for nonmotorized modes, and promotion and marketing efforts (Toor and Havlick, 2004).

The TDM actions that have proven most effective in reducing the amount of single-occupant vehicle use are those which increase the price of travel for users (Meyer, 1999). These actions can be done directly through higher parking fees or indirectly through increasing the time in which it takes to travel by automobile. The cost of travel can also be reduced for other modes, such as through improved public transit performance or financial incentives for individuals who commute via a non-automobile mode of travel. The underlying premise of any TDM is that auto users do not currently pay the full cost of their travel and receive the largest subsidies of any transportation mode in the United States (Meyer, 1999). TDM strategies can be a cost-effective means of reducing the demand for parking on a campus. One study of the implementation of a fare-free bus pass system at the University of Colorado found that it would have cost over two times as much to create an additional automobile parking space than it did to shift one person from driving to riding the bus (Toor and Havlick, 2004).

A university campus can be ideally suited to TDM strategies. University administrations are more autonomous than the multiple levels of government in an urban area. This distinction is important, as many TDM strategies can be controversial and difficult to implement. As Meyer (1999) states bluntly, "the political willingness to implement TDM actions that have any significant impact on the cost of automobile travel is generally not present in most urban areas." The members of an academic institution are typically more progressive and accepting of change. The infrastructure of campuses and surrounding areas is more likely to provide alternate options of travel if the cost of automobile commuting is increased. This last characteristic is essential, as TDM strategies will face poor success and heavy opposition if automobile users do not have a suitable alternate mode of travel.

Of course, an individual's perception of a suitable alternate mode of travel can vary greatly. The next section will explore the barriers to other forms of travel, focusing on the most sustainable modes of walking and cycling.

MODE SUITABILITY THEORY

University students, faculty, and staff can only shift to other modes of travel if the appropriate infrastructure and environments exist within and adjacent to campuses. In order to determine the potential for individuals to use alternate modes of travel, a review of existing literature regarding travel mode suitability and acceptable commute travel time was performed. The definition of suitability can be taken in fairly absolute terms: whether or not it is possible to walk, bicycle, or use transit for commute purposes based on the provided infrastructure and distance from origin to destination. This definition favors the prediction of "captured' rather than "choice" walkers and bicyclists, it most appropriately analyzes walking and bicycling potential in the context of a commuting system that discourages automobile travel.

Studies have taken different approaches in attempting to predict pedestrian or bicycling suitability. Most recently, health and urban planning researchers have examined the effect of the built environment, including urban design, on the potential to reduce automobile use through a shift to other modes of travel (Saelens, Sallis, and Frank, 2003). A number of studies have explored the environmental correlates of walking, cycling, and transit use in order to describe the role that planning and design strategies play in influencing travel behavior (Boarnet and Crane, 2001). This recent research was stimulated in part by the rising popularity of the neo-traditional development movement, the concept of designing new neighborhoods to reflect the patterns of early-twentieth-century suburban neighborhoods. Supporters of neo-traditional development claim that the transportation network and urban design characteristics of the earliest streetcar suburbs have a great potential to reduce automobile travel and encourage automobile travel (Cervero and Radisch, 1996).

In practically all cases, these studies have determined that urban form, built environment variables, and transportation system characteristics have only a small influence on predicting travel mode choice compared to the influence of socio-economic variables, personal attitudes toward transportation modes, and an individual's perceptions of the environment's suitability for a particular travel mode (Crane and Crepeau, 1998; Handy, 2005; Lund, 2003). Socio-economic variables, in particular household income and its relation to automobile ownership, have proven to be the most significant factors in predicting transportation mode choice. For example, less than 5 percent of households earning over $20,000 per year own no vehicles, while 26 percent of those earning less than $20,000 per year own no vehicles (Table 2.1: Pucher and Renne, 2003).

Table 2.1 – Vehicle Ownership by Income Class

(percent distribution within each income class)

Vehicle per Household	Household Income: Less than $20,000	$20,000 to $39,999	All Incomes
0	26.5	5	8.3
1	48.3	44.1	33.2
2	17.5	35.6	37.4
3 or more	7.7	15.3	21.1

Source: Pucher and Renne, 2003

Automobile use is highly associated with automobile availability, and the impact shows in the modal split by income class. Of households earning less than $20,000 a year, 17 percent of trips use non-motorized transportation and over 4 percent of trips use transit. For households with incomes above $20,000, less than 10 percent of trips used non-motorized transportation and approximately 1 percent used transit (Pucher and Renne, 2003). Household income and its relation to car ownership is a dominant factor in mode choice.

Many of these studies examined the effect of urban design and transportation characteristics by classifying neighborhoods into two categories: high-walkable and low-walkable neighborhoods (Leslie et al., 2005; Cervero and Radisch, 1996; Crane and Crepeau, 1998; Talen, 2002). A high-walkable neighborhood typically had higher population density, smaller lot and block sizes, a mixture of housing types and styles, considerable land-use mix, sidewalks, effective public transit, and community facilities within walking distance compared to low-walkable neighborhoods (Leslie et al., 2005). In general, these studies have found that residents of high-walkable neighborhoods walked for work or errand purposes twice as often as residents of low-walkable neighborhoods with similar socio-economic characteristics (Saelens et al., 2003);

however, these studies have faced the major limitation of self-selection: they did not account for whether residents of high-walkable neighborhoods chose to live there because they prefer to walk more often. The studies, therefore, could not prove what actually caused the difference in transportation mode choice (Handy, 2005).

In addition, studies attempting to correlate the frequency of non-automobile trips and built environment variables have often omitted the effect that specific pedestrian and cycling infrastructure might have on transportation mode choice. Land-use density, land- use mix, and street network characteristics were the most common variables used to define the walkability of a neighborhood, but actual pedestrian, bicycle, or transit infrastructure suitability were ignored. The actual suitability of particular road segments can vary greatly based on the availability of specifically non-motorized transportation infrastructure, as well as automobile traffic characteristics of the shared roadway. Models have been created to judge the suitability of the transportation infrastructure for walking and cycling use, and these models could have been incorporated as well (Landis et al., 2001; Landis et al., 1997; Dixon, 1996)

Despite the inconclusive results of recent studies attempting to explain the built environment's influence on travel mode choice, certain minimum levels of service for walking and bicycling must exist to allow for the frequent convenient use of non-automobile modes for utilitarian travel.

SUITABILITY MODELS

Suitability models for pedestrians and bicyclists have evolved over the past decade from measures typically applied for motorized facilities to variables specifically relevant to non-motorized users, environments, and trips. Until recently, transportation planning literature analyzed pedestrian and bicycling environments in the same way vehicle flow was characterized: through a capacity-based level-of-service standard. The *Highway Capacity Manual*, a standard- setting publication for the transportation planning profession, considers factors such as pedestrian flow, pedestrian density, and effective width as significant predictors of the provided level of service for pedestrians (TRB, 1994). These types of service indicators do not adequately address a traveler's perception of the safety and suitability of the transportation network for a pedestrian and bicycle travel. Unlike automobile travel, pedestrians might perceive the transportation network to be more suitable for their travel if they see other pedestrians using the same infrastructure. A level-of-service indicator that uses low pedestrian counts and excess capacity as an indicator of acceptable walking conditions might ignore important aspects of the environment that inhibit greater use by pedestrians.

Another type of approach for determining the suitability of the environment is an environmental scan. A number of organizations have developed a simplified checklist and rating system that is intended for use by residents of the community in order to determine the adequacy of infrastructure in their community (TRB Special Report 282, 2005). These environmental scans can effectively highlight deficiencies of infrastructure or dangerous network segments, but are time and personnel-intensive in their development.

In order to evaluate a transportation network's potential for use by non-motorized modes, a suitability model was needed that is more appropriate than existing measures of level of service. In the late 1990s, level-of-service models were developed for both walking and bicycling based on the actual perceptions of pedestrians and cyclists (Landis et al., 2001; Landis et al., 1997). These level-of-service models predicted a user's perceived comfort level under various traffic and infrastructure conditions for non-motorized modes of transportation. This comfort-level approach might most effectively predict the actual use of a road segment by pedestrians or bicyclists, as potential commuters decide whether the transportation network is suitable for use by walking and bicycling based on how comfortable they would feel using that mode of travel under the existing conditions. Therefore, a comfort-based level of service model is the most appropriate tool for determining whether it is practical to expect commuters to walk or bicycle within the existing transportation network. The infrastructure factor and traffic factors that proved significant in the development of these models will be discussed under the respective modes in the next section.

Aside from these basic infrastructure prerequisites, other researchers have maintained that the most important factor in travel mode choice is the cost of travel, both in terms of monetary cost and time. As Boarnet and Crane (2001, p.109) asserted, "the link between the built environment and travel is intimately tied to how urban form influences the cost of travel."

Travel time is perhaps the best predictor of travel costs for commuting by non-motorized modes, especially in environments where any mode of travel has a low perceived monetary cost of operation, such as in a university setting. When parking and transit fees are paid by semester, and walking and bicycling have virtually no user fees or operating costs, the perceived monetary cost of travel is fairly equal and negligible for any mode in the short term.

The difficult determination lies in defining the maximum time people are willing to commute by various modes and various socio-economic characteristics. For example, in a university setting, there may be a difference in acceptable travel times between faculty, staff, and students. Surprisingly little research has investigated the preferred or maximum acceptable commute times or distances for non-motorized modes. Some surveys have gathered stated preferences for maximum preferred travel time, while only a couple of data sources have provided demonstrated travel behavior as an indicator of the maximum acceptable travel times of various modes (US Census 2000, US DOT 2001). The most nationally significant data source for demonstrated travel behavior is the National Household Transportation Survey collected in 2001.

The National Household Travel Survey is the only nationally-representative and statistically-reliable source of information about the demonstrated behavior of personal travel in the United States. It included a total of 66,000 households in the 2001 survey (US DOT, 2001). This survey is administered to a sample of U.S. households every five years. This survey provided some information on demonstrated commute times and distances to work by mode. The US Census has provided some information on transportation commuting patterns, but the detail has been too coarse to provide useful information on non-motorized commuting patterns.

An internet survey conducted of Clemson University faculty, staff, and students in the fall of 2005 inquired about their preferred travel times to campus by walking and bicycling. This survey provided statistically-significant data on the preferred commute times of a university population (Boyles, 2006).

Walking and bicycling have minimum levels of service to allow the use of each mode, and different acceptable commuting distances based on each mode's speed and acceptable travel cost in terms of time. This section explores the conditions required to enable the use of walking and bicycling, including transportation right-of-way conditions and acceptable commute times for non-motorized modes.

Walking Suitability

In order to enable pedestrian commuting, transportation infrastructure must suit pedestrian travel. Identifying the factors which allow for pedestrian travel is difficult, partially due to the complex relationship between numerous built environment and socio-economic variables. A person with no other means of travel might find a road segment more suitable for walking than an individual who has another option. However, a model developed by Landis et al. (2001) might be the most advanced objective attempt to identify the right-of way factors that significantly influence a road segment's suitability for pedestrian travel.

The Landis model was developed based on a study of 75 participants walking a course that represented a broad array of traffic and roadway conditions typical of the metropolitan environment in the United States. The participants graded individual road segments in real time their judgments of how well each segment accommodated pedestrian travel according to their perception of safety. The subsequent 1,315 observations on perceptions of pedestrian safety were used to develop a model with a correlation coefficient of .85 that predicted the level of service of a roadway for walking based on measurable roadway and traffic stimuli. The model and its inputs are detailed in Equation 2.1.

Equation 2.1 - Pedestrian Level of Service Model (Landis et al., 2001)

$$PLOS = -1.2021 \ln (W_{ol} + W_l + f_p * \%OSP + f_b * W_b + f_{sw} * W_s) + .253 \ln (Vol_{15}/L) + .0005\, SPD^2 + 5.3876$$

Where:

W_{ol} = Width of outside lane (feet),
W_l = Width of shoulder or bike lane (feet),
f_p = On-street parking coefficient (=.20),
$\%OSP$ = Percent of segment with on-street parking,
f_b = Buffer area barrier coefficient (=5.37 for trees spaced 20 feet on center),
W_b = Buffer width (distance between edge of pavement and sidewalk, feet),
f_{sw} = Sidewalk presence coefficient,
= $6 - 0.3W_s$
W_s = Width of sidewalk (feet),
Vol_{15} = volume of directional traffic in 15-min period,
L = total number of through lanes,
SPD = Average running speed of motor vehicle traffic

Level-of-Service	PLOS Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

As shown in Equation 2.1, the roadway variables that proved statistically significant for the prediction of pedestrian suitability included:

- width of the outside traffic lane,
- width of shoulder,
- presence of on-street parking,
- any buffers between roadway traffic,
- the presence of a sidewalk,
- traffic volume,
- and motorist speeds.

This model is especially useful because although it incorporates the presence of a sidewalk, it gives a ranking to road segments without pedestrian facilities. This aspect is important for areas that lack sidewalks on all streets except the larger arterial roadways. The lack of specific pedestrian facilities does not necessarily prohibit pedestrian travel. There is still a potential to walk within or adjacent to the roadway if other characteristics of the roadway allow.

The other major requirement, besides pedestrian suitability, needed to predict the theoretical catchment for pedestrian commuters is travel time or distance. The average pedestrian travels at approximately 2.6 miles per hour (4.35 km/hr), a low travel speed compared to other modes of travel (Knoblauch et al., 1996). Individuals commuting for work or school are fairly time-sensitive. That is, a majority of commuters are willing to travel for only a certain amount of time before the cost in time is considered too great. Neo-traditional texts widely accept one-quarter of a mile (.40 km) as the standard distance for walking accessibility (Talen, 2002; Song and Knaap, 2004); however, this figure seems to have little supportive data, and a quarter-mile walk would take only slightly over five minutes at an average walking speed. This acceptable distance is usually cited from the book, *Accomodating the Pedestrian*, whose author cited a ten-minute walk as the "maximum distance American people are willing to walk today (Untermann, 1984). These short distances might be more applicable when examining a person's propensity to walk to neighborhood stores or access a public transit route, but this common assumption underestimates the distance an individual might be willing to commute by walking. Utterman did acknowledge that as transportation costs and traffic congestion worsen, people might be willing to walk farther distances. The traditional approach of planning for a ten-minute walk is not adequate for considering the actual time people would be willing to commute by walking.

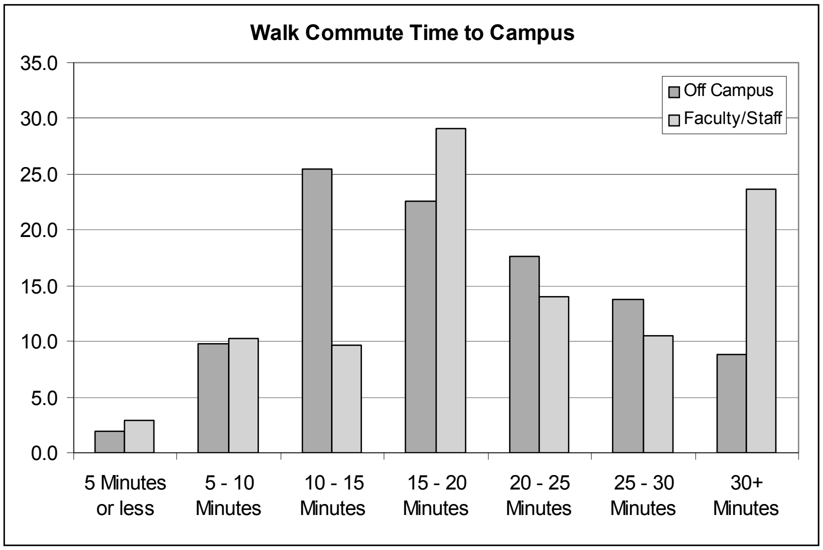
The National Household Transportation Survey (2001) offered insight into the demonstrated behavior of individuals who commuted to work by walking. The mean trip length of all walking, home-base to work trips was .96 miles, and the mean trip duration was 14.12 minutes. This distance is significantly greater than the quarter-mile figure often used in planning for pedestrian access.

Perhaps the most applicable supporting literature for acceptable walking distances to a college campus comes from studies of children's trips to school. For example, a study of middle school students' travel behavior found that a majority of children walked home from school when living with one mile of school, while 36 percent walked home if they lived 1 to 1.5 miles away

(Schlossberg et al., 2006). Fewer than four percent of children walked home from school when living beyond 1.5 miles away. How far children were willing to walk home was considered the important determinant, as the trip to school was much more biased toward the automobile as parents dropped children off at school on their way to work.

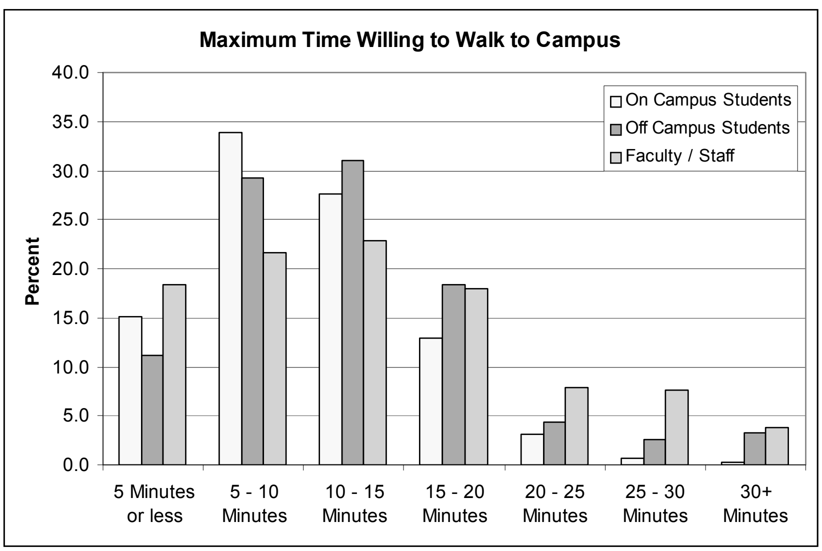
The internet survey of Clemson University faculty, staff, and students in 2005 allowed acceptable walking distances to be placed in university context (Boyles, 2006). While all trips on and to campus began and ended with a walk trip, eight percent of off-campus survey respondents regularly commuted to school by walking. Five percent of off-campus students, four percent of faculty, and one percent of staff reported commuting by walking. Boyles (2006) found that the majority of off-campus students walked twenty minutes or fewer to commute to campus (Figure 2.1). Surprisingly, faculty and staff had a longer tolerance for walk commute time, contradicting the assumption that faculty and staff might be more time-sensitive than students. These two groups did more frequently report that they considered walking a form of exercise. Boyles also explored the difference between demonstrated behavior and the stated preference for a maximum commute time by walking. The study found similarities, but on-campus students showed a striking sensitivity to commute time, as 49 percent were unwilling to walk more than 10 minutes to campus (Figure 2.2).

Figure 2.1 – Commute Time to Campus by Pedestrians



Source: Boyles, 2006

Figure 2.2 – Maximum Time Willing to Walk to Campus



Source: Boyles, 2006

Interestingly, Clemson University's *Campus Master Plan* defined a "reasonably convenient" parking distance to be within 20 to 25 minutes of one's destination, a distance that works out to 1.00 to 1.25 miles based on the plan's assumed walking speed of 3 miles per hour (*Campus Master Plan*, 2000). This "reasonably convenient" time to travel from a vehicle to a destination is greater than the amount of time the majority of students were willing to walk to campus without considering the additional commute time spent commuting in the automobile.

<u>Bicycling Suitability</u>

Bicycling might be the most difficult travel mode to forecast network suitability, as an individual's perception of cycling suitability for a trip purpose varies greatly based on experience, cultural norms, weather, and physical condition; however, university towns have proven to be the most influential predictor of bicycle commuting, perhaps due to the large populations of young and healthy students often living in close proximity to campus (US DOT, n.d.) Technically, a bicyclist could travel on any public roadway except where specifically prohibited. Realistically, a number of characteristics affect the suitability of roadways for bicycle commuting.

Again, the aforementioned research conducted by Landis et al. (1997) might be the most comprehensive evaluation of the roadway characteristics that affect the safety level of service for bicyclists. Nearly 150 cyclists completed a course representing a broad range of traffic, roadway conditions, and land development forms present in typical urban areas of the United States. These participants ranked each segment of roadway on how well it accommodated their travel based on their perceptions of safety. The result was a model with a correlation coefficient of .73. One version of the model and its inputs is detailed in Equation 2.2.

Equation 2.2 - Bicycle Level of Service Model (Landis et al., 1997)

$$BLOS = .607\ln(Vol_{15}/L) + .901\ln[\mathrm{SPD_p}(1+\%HV)] + 6.510(PC_5)^{-2} + -.005(W_e)^2 + -1.833$$

Where:

$BLOS$ = perceived hazard of the shared-roadway environment,
Vol_{15} = volume of directional traffic in 15-min period,
L = total number of through lanes,
$\mathrm{SPD_p}$ = posted speed limit
HV = percentage of heavy vehicles (as defined in the *Highway Capacity Manual),*
PC_5 = Federal Highway Administration's 5-point pavement surface condition rating, and
W_e = average effective width of outside through lane
($W_e = W_t + W_l$)
where
W_t = total width of outside lane (and shoulder) pavement, and
W_l = width of paving between the outside lane stripe and the edge of pavement

Level-of-Service	BLOS Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

As evident in the model, the significant variables for predicting a roadway's suitability for bicycle use included:

- traffic volume,
- number of lanes,
- posted speed limit,
- frequency of heavy vehicle traffic,

- pavement condition,
- and lane width (including bicycle lanes and shoulder)

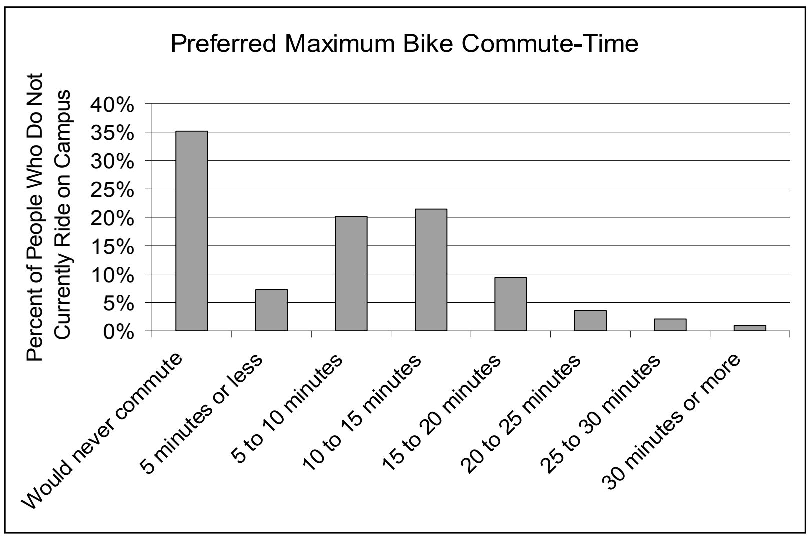
The model indirectly incorporated specific bicycle infrastructure (bike lanes) by considering it as an element of outside lane width. Including bike lanes as part of the outside lane width is a practical way to address the issue of bicycling specific infrastructure, models with high dependence on bicycle-specific infrastructure tend to underestimate the suitability for bicycling of road segments that lack bike lanes but still provide a high level of service.

The model developed by Landis et al. can identify road segments that are suitable for bicycling by choosing a specific minimal level of service that is appropriate for the projected users. A level of service D or better would typically indicate a road segment suitable for novice and experienced bicyclists, although a level of service C or better would indicate more comfortable conditions for novice cyclists.

Aside from roadway suitability, the other major factor in the theoretical ability to commute by bicycle is the time or distance to reach a destination. An average cyclist can travel at 12.5 miles per hour (Fajans and Curry, 2001). Of course, this speed can vary greatly based on traffic conditions, terrain, and the physical condition of the individual cyclist. According to the National Household Transportation Survey, the mean trip length of all bicycling, home-base to work trips was 2.85 miles, and the mean trip duration was 22.16 minutes (NHTS, 2001). A survey of subscriber's to *Bicycling* magazine in 1980 found the majority of respondents who commuted had a trip length of under 5 miles, with an average trip length of 4.7 miles (Forester, 1994).

As with the pedestrians, the Clemson internet survey explored the stated preferences of potential bicycle commuters. Survey participants who did not currently bike to campus were asked what would be their preferred bike commute time if they did bike. Thirty-five percent of respondents said they would never consider commuting by bike, while the remaining majority of people who would bike preferred a commute time of 15 minutes or fewer

Figure 2.3 – Preferred Maximum Bike Commute Time



Source: Boyles, 2006

SUMMARY

Due to the large, negative externalities created by automobile commuting, a sustainable transportation system is one which places greater emphasis on non-automobile modes of commuting. The modes of walking and bicycling could be considered the most sustainable forms of commuting due to their lack of the many negative externalities created by automobile users. Transportation demand management strategies do exist which could encourage a shift away from single-occupant automobile commuting, but the political acceptance of such strategies will depend on the commuting population's perception of alternative modes for commuting. Adequate transit service, appropriate land use patterns, and infrastructure conditions must exist in order to provide commuters with an acceptable alternative to automobile commuting.

The existing literature on non-motorized commuting has addressed the modes commuting potential through fragmented approaches. Some research has focused on the maximum distance people are willing to travel by walking or bicycling, while other researchers have focused on the transportation right-of-way conditions necessary to enable non-motorized commuting in the first place. A truly integrative approach to understanding the potential for pedestrian and bicycle commuting would combine the understanding of acceptable commute distances and infrastructure preconditions in order to understand the true potential of pedestrian and bicycle commuting in a specific area.

RESEARCH QUESTION AND OBJECTIVES

As decision makers at universities are faced with a growing demand for parking and an opposing desire of promoting sustainable transportation patterns, transportation demand management strategies may be useful tools to address the dilemma. However, a university can only encourage a shift from personal automobile commuting to other forms of transportation if a significant portion of university members can realistically commute to campus via more sustainable modes of transportation, such as walking and bicycling. Does the transportation network, land use policy, and faculty, staff, and student housing location allow for a greater percentage of commuter trips to Clemson University be made by walking or bicycling?

The objectives of this research are:

- To assess the suitability of a university community's transportation network for pedestrian and bicycling commuting within proximity to the main campus
- To calculate the number of university faculty, staff, and students who could potentially commute to the main campus by walking or bicycling, or who live within an acceptable commuting distance but are prevented from using non-motorized modes by an unsuitable transportation network

- To identify the transportation network barriers within proximity to the main campus that prevent campus members from having the option to commute by walking or bicycling

METHODOLOGY

Clemson University was chosen as the study site due to the area's representation of a typical college town environment. Furthermore, a university setting such as Clemson University represents an ideal environment in which to encourage non-motorized commuting due to the young and active student population. Furthermore, the high-density of employment, academic, and commercial uses found in a university setting make walking and bicycling ideal modes for transportation.

MAXIMUM ACCEPTABLE COMMUTE TIMES AND DISTANCES

The first step towards answering the research question stated above required defining the maximum commuting distance that most people would be willing to travel to arrive at Clemson University. The most appropriate source for identifying acceptable commuting distances was the locally-administered 2005 Clemson Travel Patterns Internet Survey. This survey directly targeted the campus community of Clemson University and inquired about the stated preferences of maximum acceptable commute times for walking and bicycling. Through the responses to this survey, a broadly-applied maximum acceptable pedestrian and bicycle commuting times was defined based on the 75th-percentile response rate. In addition, the distribution of responses among the various commute time ranges were used to infer the percentage of campus members who would commute via walking or bicycling when living within certain travel times of campus.To take these acceptable commute times a step further, average commuting speeds via walking and bicycling were used to infer the network distance away from campus that these travel times represented. By using the Network Analyst extension of ESRI's ArcGIS, the actual network distance and distribution of potential commuters was modeled by defining service areas based on the calculated network distance distributions. During these initial steps, the actual suitability of the transportation network for walking and bicycling was not considered, so the initial results represented an idealized best-case scenario of the potential commuting catchments of walking and bicycling to Clemson University.

NETWORK SUITABILITY FOR WALKING AND BICYCLING

In order to reflect realistic commuting decisions, the suitability of the network for walking and bicycling was then assessed. The level-of-service models developed by Landis et al. (2001) and Landis et al. (1997) (Equations 2.1 and 2.2) for walking and bicycling, respectively, were used to assess the suitability of the transportation infrastructure for these modes of travel. These models considered roadway infrastructure and traffic characteristics to assess pedestrian and bicycle suitability. The data for these models were gathered through a combination of archived public data, field work, assumptions, and forecasts as discussed in the following chapter.

It is important to remember that these level-of-service models essentially illustrated a user's perceived comfort of the roadway, instead of the traditional level-of-service concept modeling facility capacity and traffic flow. However, a comfort-based level-of-service model would be the best way to determine actual use or suitable conditions for non-motorized modes of transportation because issues of comfort substantially affect selection of non-motorized modes. Commuters would likely decide whether to travel by walking or bicycling based on whether they felt comfortable doing so on the given transportation network. Therefore, a comfort-based index provided the most appropriate means of predicting whether the network was capable of accommodating pedestrian and bicycle commuting.

WALKING AND BICYCLING COMMUTING CATCHMENTS

The next step involved combining the maximum acceptable network commute distances with the suitable roadway segments identified by the level of service models to identify the actual commuting catchments for walking and bicycling. The output represented the current commuting catchments from which individuals could be expected to commute via walking or bicycling to the core campus of Clemson University based on distance and suitability. City of Clemson parcel data were then used to select which parcels had access to both the theoretical commuting catchments for walking and bicycling based on maximum acceptable commuting distance and the actual catchments taking into consideration commuting distances along suitable roadway segments only.

CAMPUS MEMBER COMMUTING POSSIBILITIES

After the theoretical walking and bicycling commuting catchments were determined, year 2005 address information for faculty, staff, and students were geocoded through ArcGIS to develop a geographic representation of the home address locations of Clemson University commuters. These address points were then identified as being within the actual commuting catchments of walking or bicycling, theoretical commuting catchments of walking or bicycling, or outside of walking or bicycling distance. Further calculations were performed to estimate how many off-campus commuters should currently be expected to commute by walking and bicycling, in addition to how many more could commute by walking or bicycling if the unsuitable network segments were improved to provide an adequate level of service.

CATCHMENT LAND USE POLICY CHARACTERISTICS

Finally, an analysis of the land-use characteristics and policies of the City of Clemson parcels within the commuting catchments was performed using the City of Clemson's "Future Land Use" map to explore the relative role that land-use policy might make facilitating greater pedestrian and bicycling commuting to Clemson University.

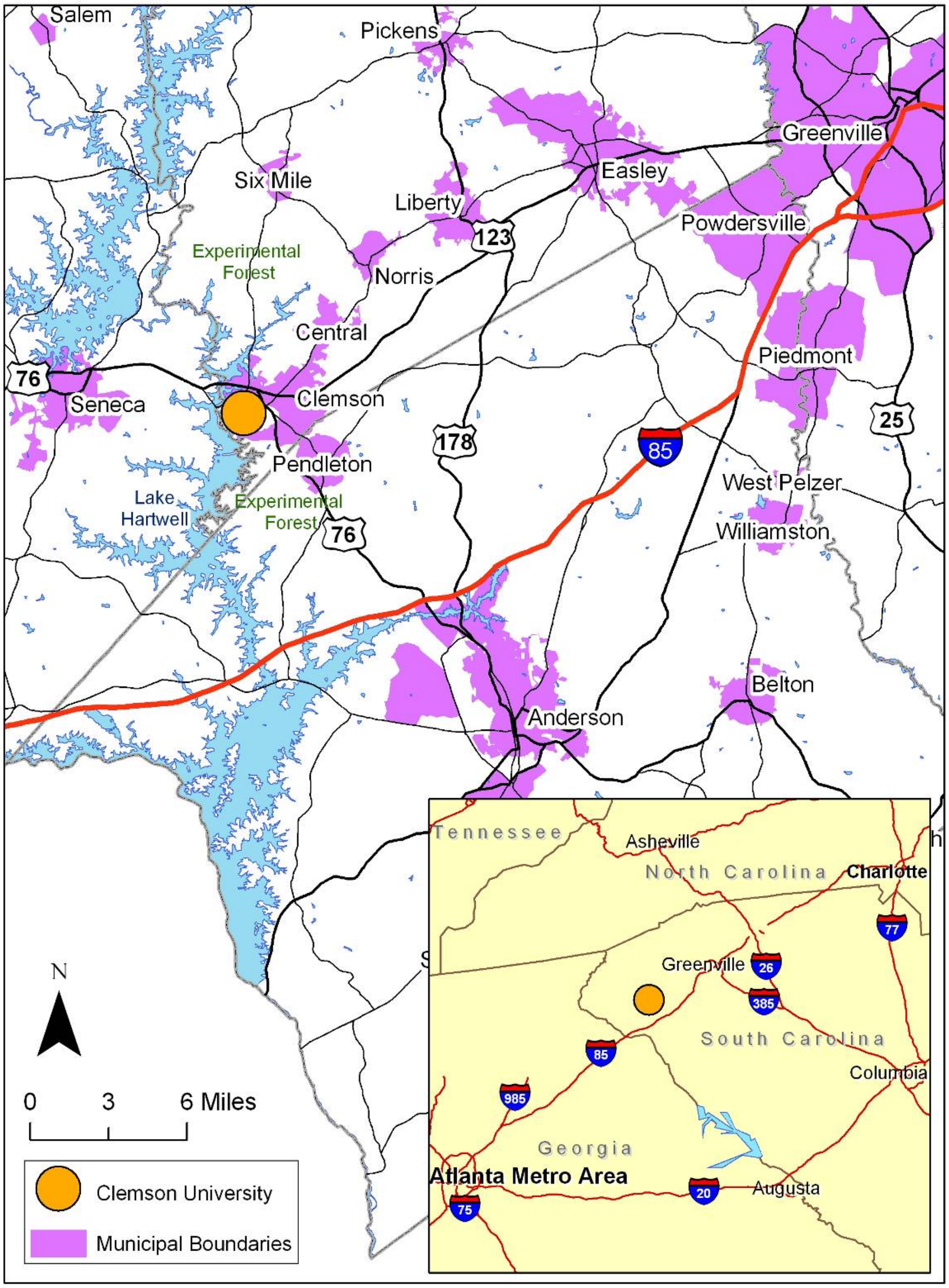
CLEMSON UNIVERSITY AND THE REGION

Clemson University is a public land-grant university in a college-town setting in the Upstate of South Carolina. The main campus includes 1,445 acres in the Southwestern tip of Pickens County and is bordered by Lake Hartwell on the West and the City of Clemson to the North and East. The Clemson Experimental Forest and various agricultural land owned by Clemson University border the main campus to the South. Clemson University's regional context is illustrated in Figure 5.1 (next page).

The university had an enrollment of just over 17,000 students in 2005, including slightly over 3,000 graduate students (Clemson University, 2005). A significant number of Clemson students were international students (4.6 percent), a population often dependent on transit and non-motorized modes of transportation for mobility.

The main campus can house approximately 6,600 students on site, 42 percent of the student population (Campus Master Plan, 2002). The remaining percentage of students and all faculty and staff have commuted to campus with large portions of the off-campus student body residing either in the city of Clemson or the town of Central, the municipality immediately adjacent to the city of Clemson in the Northeast.

Figure 5.1 – Clemson University within the Region



The transportation characteristics of University members and the region as a whole has undoubtedly been auto-oriented. The “Clemson University Travel Patterns” survey conducted in 2005 of University students, faculty, and staff found that 81 percent of University members traveled to Clemson by automobile, including those who traveled by single-passenger or multi-passenger automobiles, and people who chose to park and ride (Table 5.1). When the survey was conducted, the only formal park-and-ride locations existed in peripheral parking lots on campus, so these respondents most likely arrived on campus via automobile.

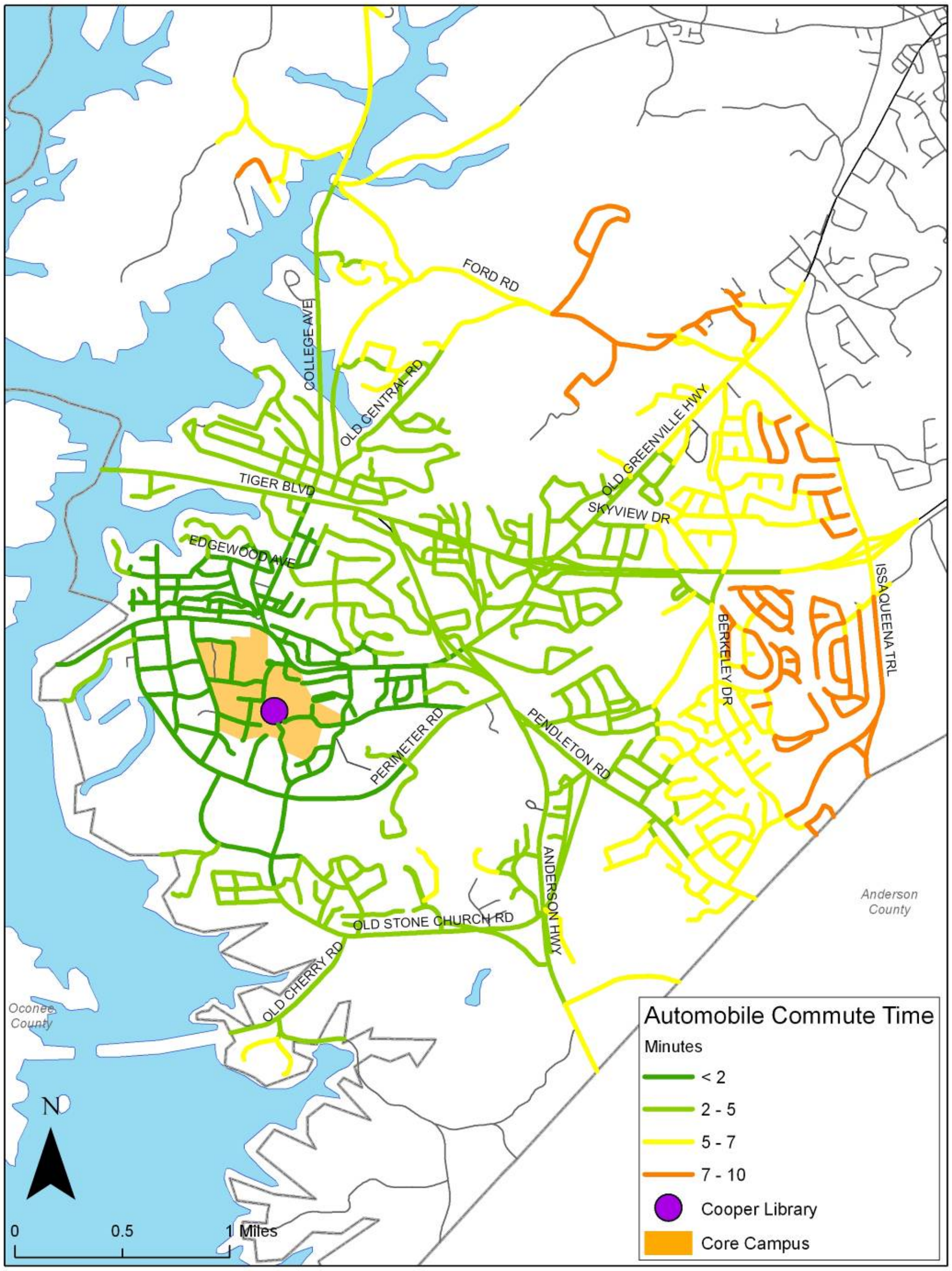
Figure 5.2 (next page) is an estimate of the time it would take to reach campus by automobile from the local area. While speed limits are taken into account for this travel time, the additional time required to find a parking spot and travel into the core campus was not considered, and could add a considerable amount of time to an automobile traveler’s commute.

Table 5.1 - Mode of travel to Clemson University, 2005

	Faculty	Off-Campus Student	On-Campus Student	Staff	All Classes
Single passenger automobile	85%	67%	17%	79%	57%
Multi-passenger automobile	7%	17%	15%	16%	15%
Park and ride	0%	17%	4%	0%	9%
Bus	4%	7%	4%	1%	5%
Walk	4%	5%	55%	1%	12%
Bike	1%	3%	3%	1%	2%
Other	1%	1%	1%	0%	1%

Source: Boyles, 2006

Figure 5.2 – Auto Commute Time to Clemson University



What might be the most surprising results of the Clemson University mode split is the relatively high use of automobiles by on-campus students to arrive at the university. Table 5.1 indicates that 36 percent of on-campus students commuted by single-passenger automobile, multi-passenger automobile, or park-and-ride. Some residence halls and on-campus apartment buildings are located relatively far from the center of campus; therefore, students living in them have felt compelled to use automobiles to arrive closer to academic buildings. These students might also have considered automobiles simply more convenient than other modes.

The 2005 transportation mode split of Clemson University mirrored the region's traveling habits (Table 5.2). In the Greenville-Spartanburg-Anderson Metropolitan Statistical Area, of which the Clemson area is a part, 95 percent of trips to work were by automobile. This dependence on automobiles for commuting was slightly higher than in the overall state of South Carolina and higher than the total for the United States.

Table 5.2 - Means of Transportation to Work, 2000

	United States	South Carolina	Greenville-Spartanburg-Anderson MSA	Clemson Urban Cluster	City of Clemson
Car, truck, or van:	88%	93%	95%	89%	91%
Public transportation:	5%	1%	0%	1%	2%
Motorcycle	0%	0%	0%	0%	0%
Bicycle	0%	0%	0%	0%	1%
Walked	3%	2%	2%	7%	4%
Other means	1%	1%	1%	1%	1%
Worked at home	3%	2%	2%	2%	1%

Source: U.S. Census

Related to this high degree of automobile commuting, Clemson University has struggled with a perceived lack of parking for students, faculty, and staff, despite the university providing a generous supply of parking compared to other universities. The Clemson campus averaged about 83 parking spaces per 100 students in 2001, well above the national average of 55 spaces per 100 students for a comparison of eighty similar academic institutions (*Campus Master Plan*). A parking utilization study conducted in 2006 found 13,018 parking stalls on campus with a peak-hour average occupancy of 78 percent (Campus Planning Services, 2006). The study found that the campus actually provided an abundance of parking, just perhaps not in the most convenient areas.

Clemson University's strategy of locating parking on the periphery of campus could impose extra travel time to reach campus buildings on the interior of the campus. Clemson's *Campus Master Plan* defined a "reasonably convenient" parking distance from one's destination as 20 to 25 minutes, a time much longer than most automobile users have been accustomed to traveling between their cars and destinations. Consequently, the lack of perceived parking supply has generally emerged from a lack of "convenient" parking close to one's destination as expected by the individual automobile commuter. Clemson University's 2002 *Master Plan* suggested while the campus is essentially pedestrian friendly, both vehicular and pedestrian circulation could be improved by eliminating what little parking does exist in proximity to the center of campus and expanding lots on the periphery (*Campus Master Plan*). The campus planners emphasized the importance of separating pedestrians from other modes of travel in order to improve the walking experience within the campus.

The *Master Plan* identified some existing large parking lots as sites for future academic buildings (Campus *Master Plan*). Universities have commonly considered large parking lots as placeholders for future building expansion (Toor and Havlick), but the loss of available parking when construction takes place has created contentious issues, as administrators have faced the choice of surface lot construction even further from the core campus or the expensive construction of structured parking.

Clemson University has currently planned for construction of its first parking structure. University administration has implemented a new student transit fee with the approval of student government ($33.50 per semester for every student) to provide funding for the fare-free Clemson Area Transit service operated by the City of Clemson. Transit funding previously came from University Parking Services, but this new fee was intended to allow Parking Services revenue to be used for parking improvements, including the funding of a new parking structure (Denny, 2006).

In terms of the University's vision for the future of transportation and its relationship to sustainability, the *Campus Master Plan* set forth a goal of advancing the concept of a pedestrian campus; however, the plan did not extensively address either the issue of how people actually arrive *on* campus or the growing demand gor parking. The "Ten Principles of Parking" published in the *Campus Master Plan* highlighted a supply-oriented approach, despite the intentions of a pedestrian-friendly campus and the emerging emphasis on a sustainable university. Principles six and seven contained the only mention of a potential reduction in the demand of parking.

- Principle one: "There should be reasonably convenient, safe and consistently reliable parking options for *everyone* in the campus community…"
- Principle six: "Operating within the framework of principle one, consistently reliable public transit service is integral to the success of an overall parking system."
- Principle seven: "Walking, bicycling, and other alternatives to single-occupancy vehicle use should be encouraged." (*Campus Master Plan*, p.66)

Planning for Clemson University has emphasized that travel *within* the campus should be sustainable and pedestrian, but neither the *Campus Master Plan* or any other official campus planning document have addressed the sustainability of transportation patterns to the campus. This oversight requires attention because the university stands to gain economic and environmental benefits by reducing the growing demand for parking while living up to the administration's emphasis on sustainability.

RESEARCH FINDINGS

MAXIMUM ACCEPTABLE COMMUTE TIMES AND DISTANCES

In order to define the theoretical maximum commute distances for walking and bicycling to Clemson University's main campus, this research used local stated preferences from the 2005 Clemson Travel Patterns Internet Survey, combined with an average commuting speed for each mode as determined in the literature. The survey results were used in two ways:

- to define a 75^{th}-percentile preferred maximum acceptable commute time that identified the maximum distance that commuters could be expected to walk or bicycle to campus.
- to indicate what proportion of residents within a given distance should be expected to commute via walking or bicycling, assuming the transportation network allowed them to do so.

It is important to mention that the maximum time people are willing to commute by walking and bicycling could vary greatly depending on, among other things, the weather and the season. The Clemson Travel Patterns Survey was conducted in late Fall, a season which provides generally ideal weather conditions for non-motorized commuting including mild temperatures and infrequent precipitation. For days and seasons that are less conducive to pedestrian and bicycle commuting, the availability of an effective transit service is an essential asset.

The 75th-percentile maximum commuting distances were calculated as a *network* distance of .65 miles for walking and 3.125 miles for bicycling (Tables 6.1 and 6.2). These distances were calculated based on the following conditions:

- Responses from faculty, staff, students to the questions of how long (in time) survey respondents would be willing to walk and bicycle to campus, excluding those respondents who indicated they would never walk or bicycle to school (Tables 5.1 and 5.2, respectively)
- 75th-percentile for acceptable commute times via walking and bicycling for all classifications, rounding down to the lower time category, excluding those respondents who indicated they would never walk or bicycle to school
- Average commuting speed for
  - Walking: 2.6 miles per hour (Knoblauch et al., 1996)
  - Cycling: 12.5 miles per hour (Fajans and Curry, 2001)

Table 6.1 - Maximum Time Willing to Walk to Campus

	All Classes		
Time	Frequency	Percent of Total	Cumulative Percentage
5 Minutes or less	167	15%	15%
5 - 10 Minutes	330	29%	44%
10 - 15 Minutes	318	28%	72%
15 - 20 Minutes	189	17%	89%
20 - 25 Minutes	59	5%	94%
25 - 30 Minutes	41	4%	98%
30+ Minutes	28	2%	100%
Total Willing to Walk	1132		
Average Walking Commute Speed		2.6	mph
75 percentile Acceptable Walking Commute Time		15	minutes
Maximum Walking Commute Distance		**0.65**	**miles**

Note: Excludes respondents who indicated they would never commute by walking

Table 6.2 - Maximum Time Willing To Bike to Campus

	All Classes		
	Frequency	Percent of Total	Cumulative Percent
5 minutes or less	70	11%	11%
5 to 10 minutes	202	31%	42%
10 to 15 minutes	212	32%	74%
15 to 20 minutes	99	15%	89%
20 to 25 minutes	37	6%	95%
25 to 30 minutes	23	4%	98%
30 minutes or more	10	2%	100%
Total willing to bike	653		
Average Bicycle Commute Speed		12.5	mph
75 percentile Acceptable Bicycle Commute Time		15	minutes
Maximum bicycling commute distance		**3.125**	**miles**

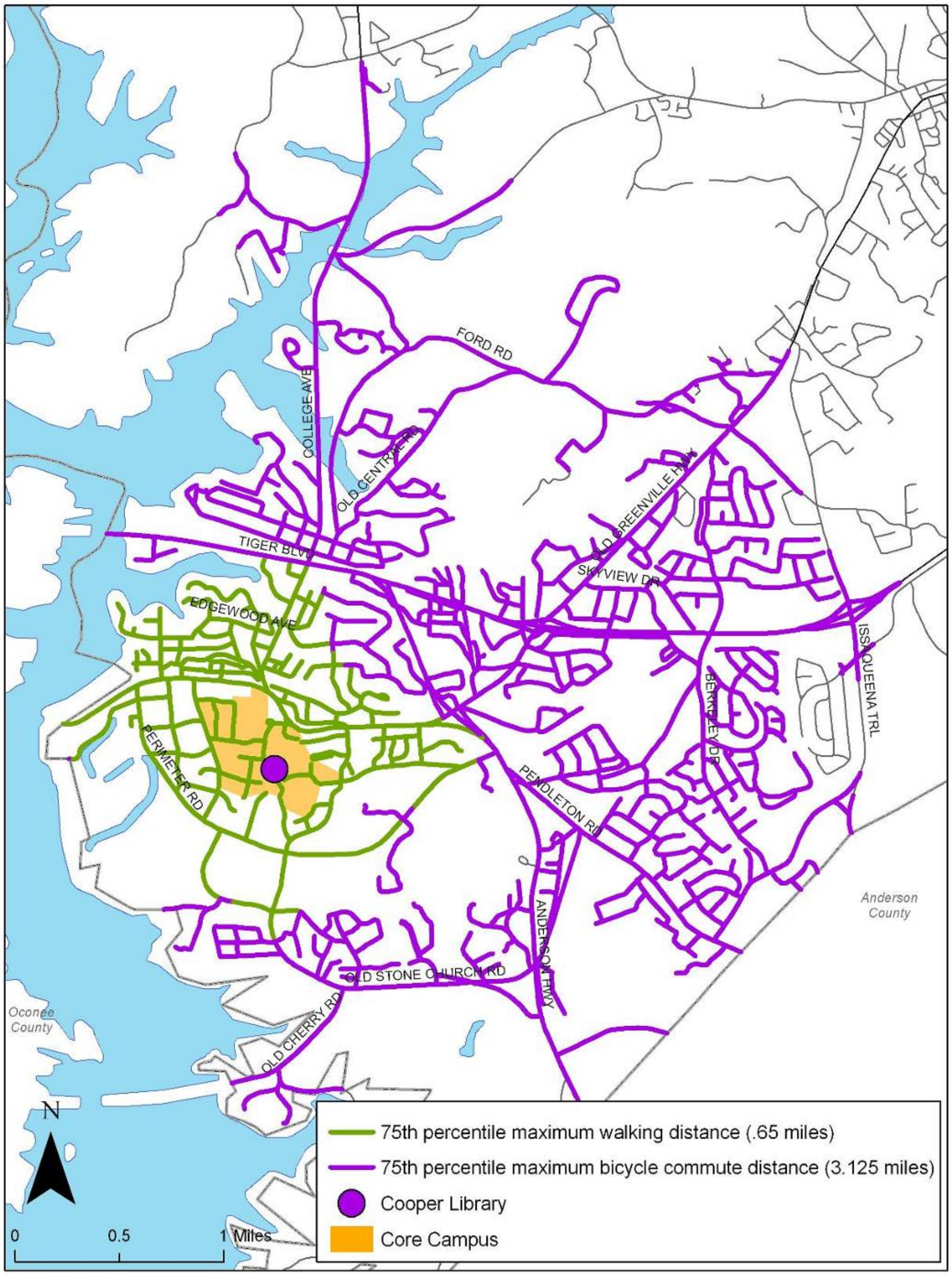
Note: Excludes respondents who indicated they would never commute by bicycle

Using the above calculated maximum acceptable commute distances and the Network Analyst extension of ArcGIS, road segments that fell within a network distance of 3.125 miles of an intersection were identified as the study area segments for which data were collected to develop the level of service model. Figure 6.1 (next page) illustrates the 75th-percentile maximum acceptable commute distances for walking and bicycling to the core campus. This figure represents the first part of identifying the theoretical commuting catchments for walking and bicycling. The second part of identifying the commuting catchments required calculating the level of service provided to non-motorized modes of transportation within this network to determine whether the transportation network within the maximum commute distances for walking and bicycling would be perceived to be suitable for travel by these modes.

Perimeter intersections of the core campus were chosen as points that represented an “arrival” onto the main academic and employment section of Clemson

University. This core campus is illustrated in Figure 6.1 by the orange polygon. This polygon was derived from the definition of the core campus that appears in Clemson University's Campus Master Plan. The network distances illustrated in Figure 6.1 represent the distance to the *closest* arrival intersection. This method underestimated the actual distance most people would need to travel to reach their ultimate destination in the campus. However, the additional distance from these perimeter locations to an interior, core-campus academic building would typically be less than the additional distance an automobile commuter would have to travel from their parking space on the periphery to the interior of campus. In addition, bicycle and especially pedestrian travel are typically less limited and more direct when commuters reach the core campus, as there is additional non-motorized infrastructure and informal paths off of the road network that lessen the network distance while traveling within the core campus.

Figure 6.1 – Maximum Commute Distances



To explore the concept of acceptable commuting distances further, the distribution of potential commuters by network distance was used to examine what percentage of commuters would commute via walking or bicycling depending on the distance from the perimeter of the core campus. For this distribution, it was appropriate and necessary to include those survey respondents who indicated they would never walk or bicycle to school in order to reflect how many commuters would realistically commute to school by distance accurately. Tables 6.3 and 6.4 illustrate the distribution of responses by distance and university affiliation, including people who indicated they would never commute by walking or bicycling. Presumably, respondents who would commute 15 to 20 minutes by bicycle would also commute 5 minutes or less, so the cumulative percent of respondents calculated towards the lower distances was used as the representation of how many commuters within a given time or distance zone would be willing to commute via that mode. The equivalent distances were calculated for each time category by taking the median time of the category multiplied by the average commute speed of the mode as described earlier.

For the walking distribution, an adjustment was needed to account for the survey's omission of not providing off-campus students, faculty, and staff respondents the option of choosing that they would never walk to school. For Table 6.3, the only actual respondents for the category of "None, I would never commute by walking" came from the on-campus students, indicating their preferences if they moved off campus. The respondents for the other categories were generated by assuming the ratio of on-campus students to off-campus students and faculty/staff for respondents who would never walk would be the same as the ratio for non-bicycle commuters. These ratios were used to generate the percentage of respondents who would have selected the "None, I would never commute by walking" option had there been one. This percentage was then removed from the next most restrictive category, the "5 minutes or less category" under the assumption that respondents who would have chose the "None, I would never commute by walking" option instead chose the "5 minutes or less category."

As Tables 6.3 and 6.4 show, on-campus students appeared to be the most time-sensitive in terms of commute time by walking and bicycling. Faculty, staff, and off-campus students exhibited a similar time-sensitivity to commuting by walking, although a substantially larger percentage of faculty and staff were willing to walk over 15 minutes. Almost one-half of faculty and staff were unwilling to commute by bicycle at any distance, while only 27 percent of off-campus students were not willing to bicycle-commute.

Figures 6.2 and 6.3 spatially show the overall potential distribution of walking and bicycling commuters, respectively. For example, of the Clemson University commuters living adjacent to the yellow network segments of Figure 6.3, 27 percent could be expected to commute by walking if the transportation network was suitable for them to do so. Specifically, commuters who lived *adjacent* to a network segment would be considered to live within the specified network distance.

Table 6.3 – Potential Pedestrian Commuter Distribution

Maximum Commute Time	Equivalent distance (miles)	Classification: On-Campus Students			Off-Campus Students			Faculty/Staff			All Classes		
		Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent
Would never commute by walking	0.0	26	6%	N/A	16	4%	N/A	25	7%	N/A	67	6%	N/A
5 minutes or less	0.1	63	15%	94%	28	7%	96%	35	10%	93%	126	11%	94%
5 to 10 minutes	0.3	141	34%	79%	115	29%	89%	74	21%	83%	330	28%	83%
10 to 15 minutes	0.5	115	28%	45%	122	31%	60%	81	23%	62%	318	27%	55%
15 to 20 minutes	0.8	54	13%	17%	72	18%	28%	63	18%	38%	189	16%	27%
20 to 25 minutes	1.0	13	3%	4%	17	4%	10%	29	8%	20%	59	5%	11%
25 to 30 minutes	1.2	3	1%	1%	10	3%	6%	28	8%	12%	41	4%	6%
30 minutes or more	1.3	1	0%	0%	13	3%	3%	14	4%	4%	28	2%	2%
Total		416	100%		393	100%		349			1158	100%	

Table 6.4 – Potential Bicycle Commuter Distribution

Maximum Commute Time	Equivalent distance (miles)	Classification: On-Campus Students			Off-Campus Students			Faculty/Staff			All Classes		
		Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent	Respondents	Percent of Total	Cumulative Percent
Would never commute by bike	0.0	139	40%	N/A	104	27%	N/A	144	47%	N/A	387	37%	N/A
5 minutes or less	0.5	29	8%	60%	33	9%	73%	8	3%	53%	70	7%	63%
5 to 10 minutes	1.6	79	23%	52%	85	22%	65%	38	13%	50%	202	19%	56%
10 to 15 minutes	2.6	66	19%	29%	99	26%	43%	47	15%	38%	212	20%	37%
15 to 20 minutes	3.6	21	6%	10%	43	11%	17%	35	12%	22%	99	10%	16%
20 to 25 minutes	4.7	9	3%	4%	15	4%	6%	13	4%	11%	37	4%	7%
25 to 30 minutes	5.7	5	1%	1%	6	2%	2%	12	4%	6%	23	2%	3%
30 minutes or more	6.3	0	0%	0%	3	1%	1%	7	2%	2%	10	1%	1%
Total		348	100%		388	100%		304	100%		1040	100%	

Figure 6.2 – Pedestrian Commuter Distribution

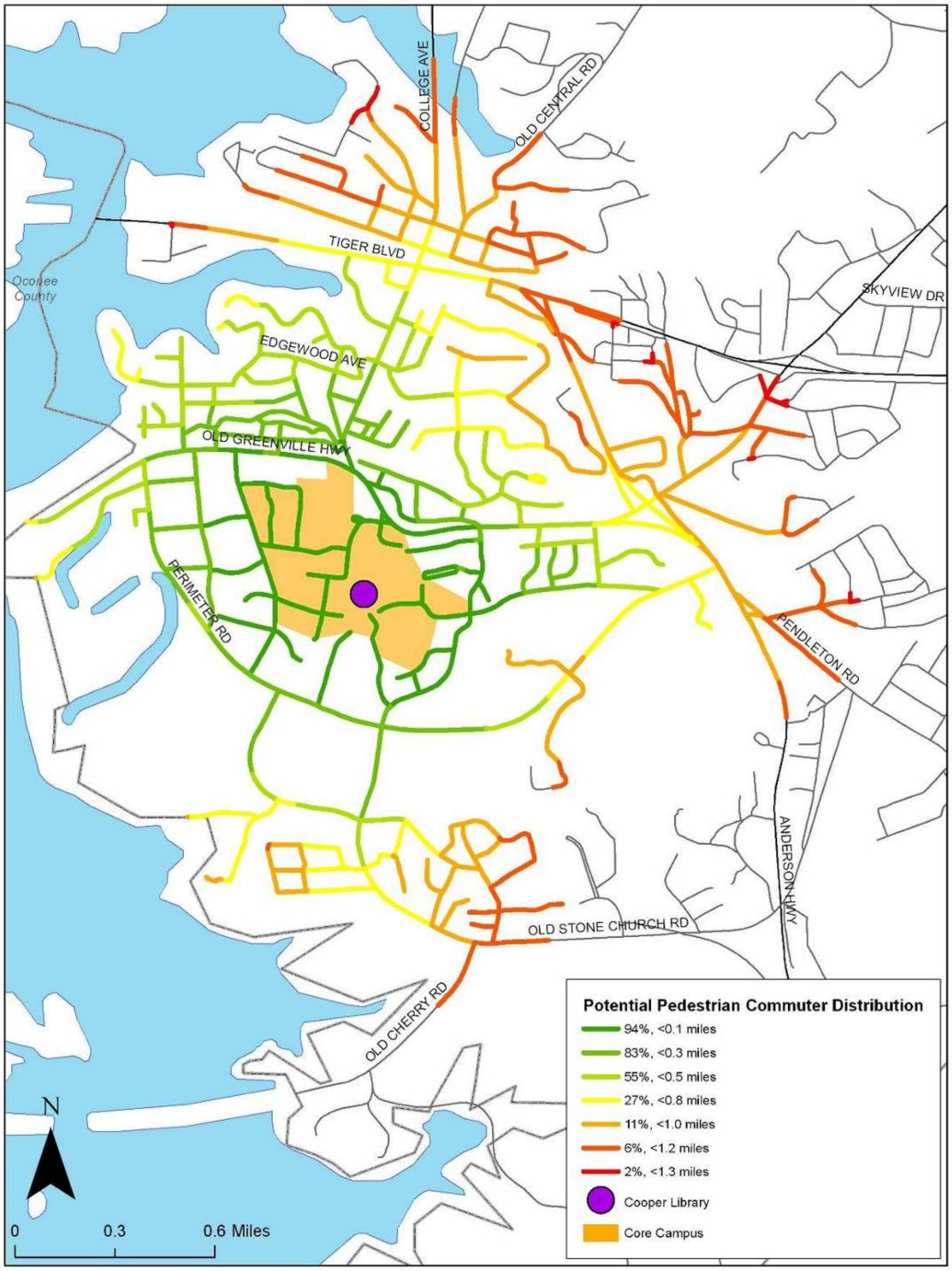
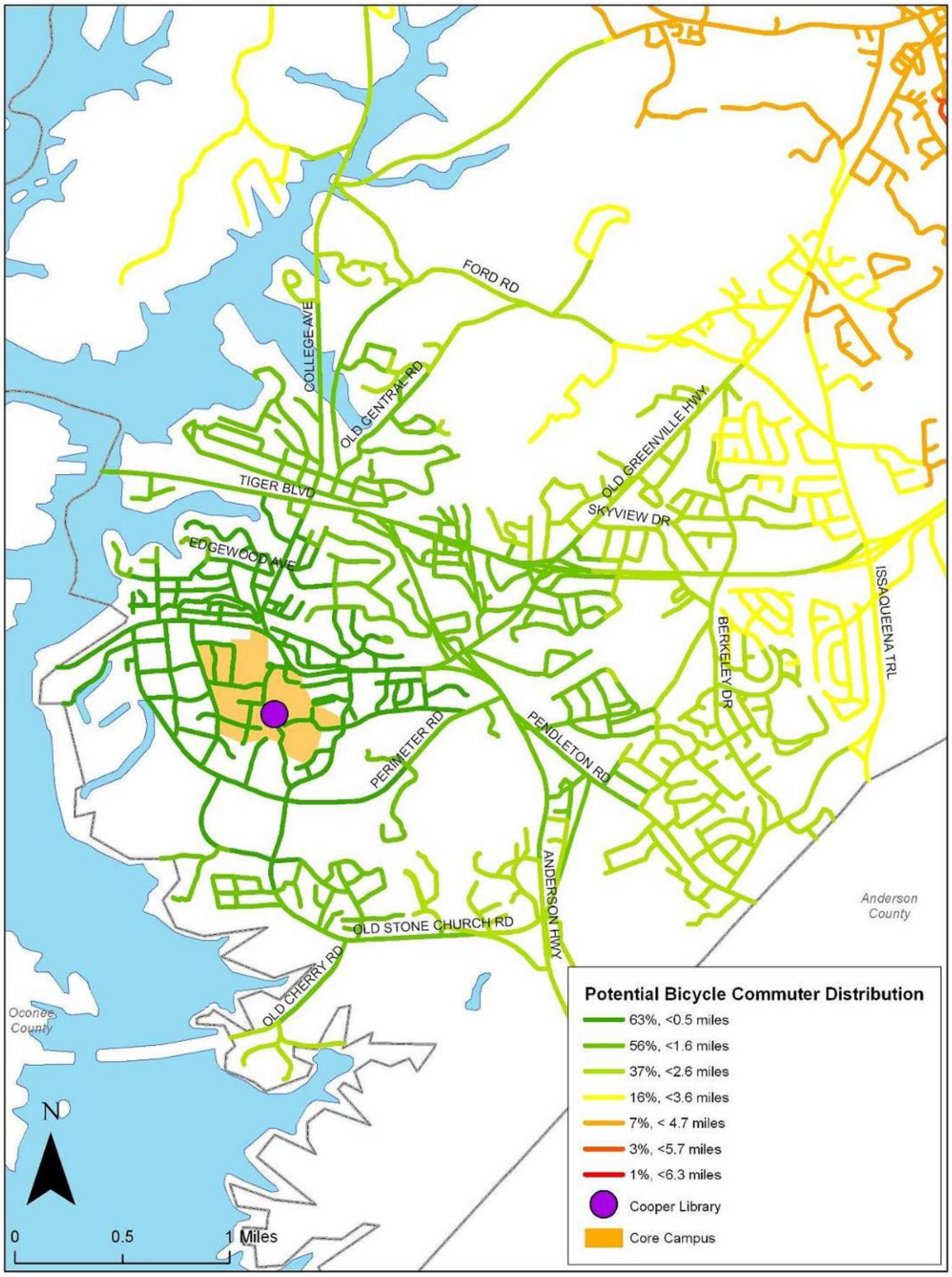


Figure 6.3 – Bicycle Commuter Distribution



NETWORK SUITABILITY FOR WALKING AND BICYCLING

In order to calculate the level of service provided by the road network to pedestrians and bicyclists, the parameters used in the level-of-service models developed by Landis et al. (2001, 1997; see equations 2.1 and 2.2) were collected for each road segment of the study area. The data gathered through a field inventory included:

- number of lanes (Ln),
- posted speed limit (SPp),
- pavement condition rating (PR5),
- width of outside through lane (Wt),
- width of paved shoulder or bike lane (W1),
- percent of segment striped for on-street parking (OSPA),
- width of buffer between sidewalk and street (Wb), and
- width of sidewalk (Ws).

In addition to these manual measurements, the one remaining parameter required for the level of service models was automobile traffic volume, which was obtained from a few different sources as discussed later.

All of these parameters were generated for each road segment that was within a network distance of 3.125 miles (the 75th percentile maximum acceptable commute distance as defined in the previous section) of an intersection at the perimeter of Clemson University's "core campus" as illustrated in the *Campus Master Plan*.

While gathering the data required for the level-of-service models, the following assumptions were made, some for simplification purposes, while others to ensure a realistic level-of-service rating:

1) The data were gathered at only one cross-section per road segment. The cross-section was chosen based on how well it represented the dominant conditions of that particular road segment. For example, a segment that had sidewalks and bike lanes for less than a majority of the length of segment was scored as having no sidewalks or bike lanes. This assumption had the effect of omitting isolated segments of sidewalk infrastructure that in reality provided little pedestrian connectivity.
2) Intersections were not scored in the level-of-service formula, nor were they included separately. An assumption was made that the level of service of intersections was comparable to the level of service of the road segments which joined to form the intersections.
3) Road segments were not scored separately in each direction. To account for the possible omissions this assumption may have made, bicycle infrastructure was rated on a "worst-case" scenario. For example, the direction that had the narrower outside lane and narrower shoulder or bike lane were recorded. This worst-case scenario is appropriate for the bicycle level-of-service rankings because bicyclists are directionally restricted. That is, they are supposed to travel with the direction of automobile traffic. This assumption might have tended to underestimate overall system level of service if bicyclists chose different routes for different

directions in cases where the roadway provides an acceptable level of service in one direction but not the other. Pedestrians are not directionally restricted, and therefore, pedestrian infrastructure was scored on a “best-case” scenario to account for the fact that pedestrians are able to and most likely will cross a street to travel on the side that is most suitable for pedestrian travel, regardless of the direction of automobile traffic.

4) Actual, measured traffic volumes were only available for road segments that were maintained by the South Carolina Department of Transportation. These roads included: US 123, US 76, US 76 BUS, SC 93, and SC 133. To develop traffic volumes for the remaining roads, two resources were used. The projections from a travel demand model developed by a group of Clemson University graduate students for a travel demand modeling class were used for suburban collectors and other locally important roads that did not have actual traffic count data (Mattox et al., 2005). This model projected automobile traffic volume on many of the suburban collectors that did not have actual traffic count data. For the roads which were not modeled by this group, which included most of the local roads in the study area, assumptions on traffic volume were used based on the classification of the roadway (Toole Design Group, 2003).

The final level-of-service outputs have been categorized into six rankings, with A representing an excellent level of service and F representing an entirely unsuitable level of service for any user. Table 6.5 details the breakdown of level of service by model score for both the pedestrian and bicycle models. For the purposes of this study, a level of service C or better was considered suitable for travel by that particular mode of travel. A ranking of C is intended to represent the minimum level of service and comfort required before a novice pedestrian or bicyclist would consider using the roadway. Figure 6.4 illustrates the levels of service for pedestrian travel, while Figure 6.8 illustrates the levels of service for bicycling in the Clemson area.

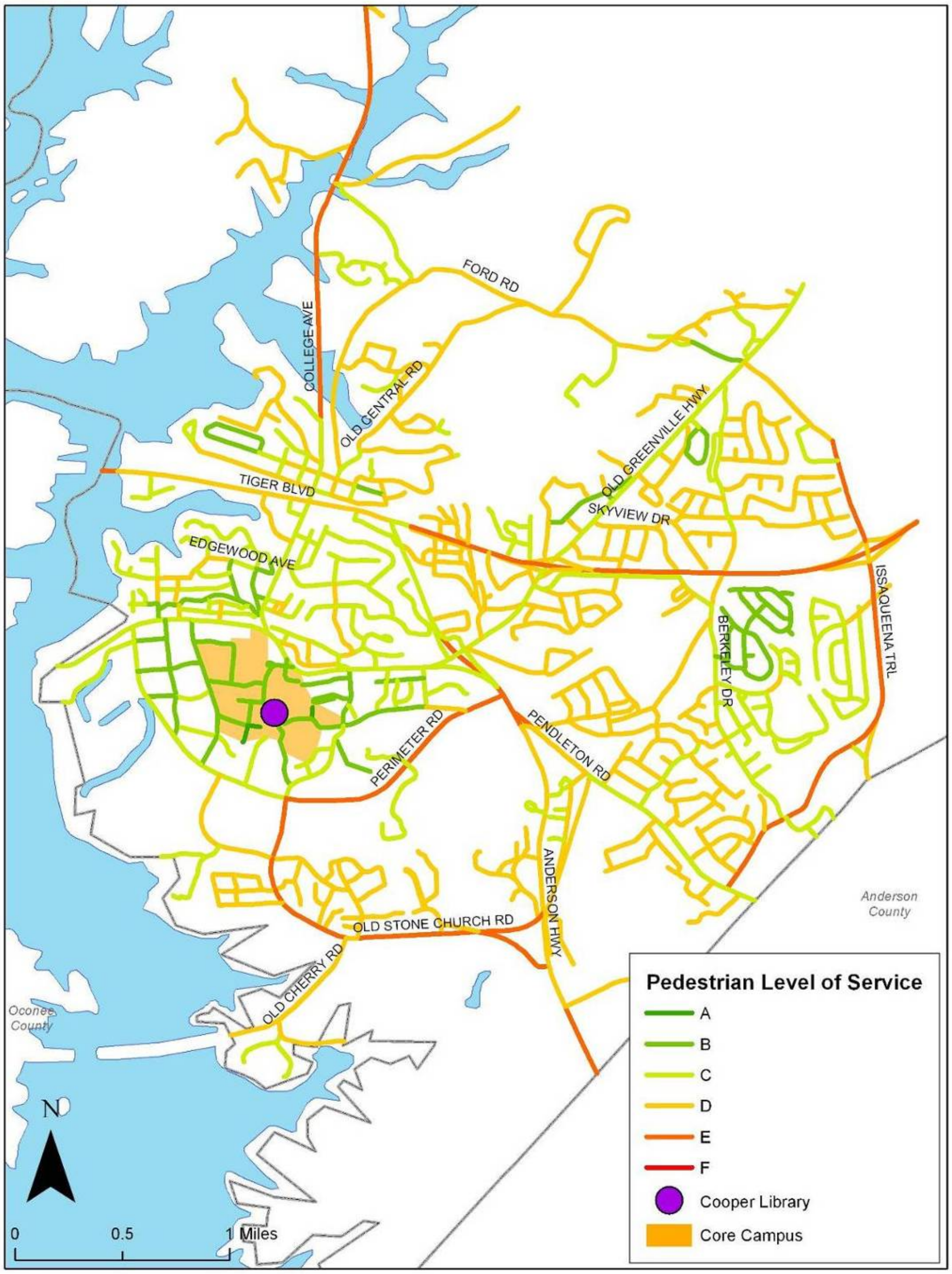
Table 6.5 – Level of Service Score

Level -of-Service	Model Score
A	< 1.5
B	> 1.5 and < 2.5
C	> 2.5 and < 3.5
D	> 3.5 and < 4.5
E	> 4.5 and < 5.5
F	> 5.5

It should be mentioned that due to the way in which these level-of-service models were developed by Landis et al., the results essentially indicated the average comfort level provided to pedestrians or bicyclists. Of course, people's individual perceptions of comfort will vary not only relatively, but also subjectively. For example, one person might prefer walking on an arterial high-volume roadway that provides dedicated pedestrian infrastructure while another person might prefer walking along a low-volume local roadway that does not have sidewalks. These two people might disagree with each other's perception of pedestrian suitability among various network typologies. Therefore, it is important to keep in mind that the level-of-service outputs represented the average perception of pedestrian and bicyclist comfort and suitability.

For someone familiar with the study area, the results of Figure 6.4 make intuitive sense. The road segments ranked as level of service A or B all possessed sidewalks and supported relatively low vehicle volumes and low speeds. The arterial roadways that possessed sidewalks were ranked, at best, a level of service C such as Old Greenville Highway. Tiger Boulevard, the largest-volume roadway within the study area, was ranked as a Level of Service D. The difference in score between Old Greenville Highway and Tiger Boulevard also made intuitive sense. Old Greenville Highway has frequently attracted recreational running and walking along its sidewalks, while Tiger Boulevard rarely has inspired pedestrian travel along its sidewalks. These two arterial roadways differ in two respects in terms of the model: 1) Old Greenville Highway has a two-to-four foot bike lane serving as a buffer between automobile traffic and pedestrian traffic, and 2) Tiger Boulevard has experienced approximately 10,000 more vehicle trips per day.

Figure 6.4 – Pedestrian Level of Service



The road segments within the campus itself provided a relatively good level of service, while local roads within the city of Clemson generally did not provide an acceptable level of service to pedestrians. Importantly, the major access roads in proximity to Clemson University were mostly ranked as a level of service C or better. For example, College Avenue, the major road providing access from the north to Clemson University and the location of downtown Clemson, provided a direct, level-of-service C connection to the core campus. Figure 6.5 is a picture of College Avenue just south of the intersection with Tiger Boulevard. The relatively wide sidewalks and wide outside travel lanes contributed to the Level of Service ranking of C.

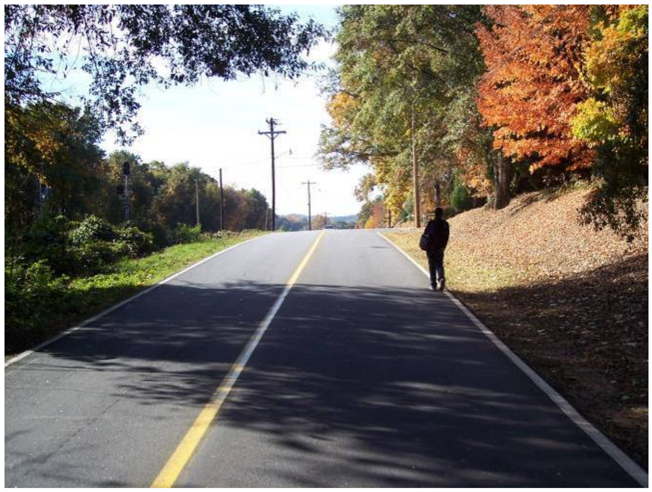
Figure 6.5 – College Avenue, City of Clemson

The two access roads to the core campus that stood out as unsuitable to pedestrians with a level of service of E were Old Stone Church Road and Perimeter Road on the south and southeast sides of campus. As evident in Figure 6.6, Old Stone Church Road was characteristic of the rural nature of the area south of campus, with no pedestrian amenities and high traffic speeds. Perimeter Road was very similar in nature.

Figure 6.6 – Old Stone Church Road, City of Clemson

Local residential roads within the city of Clemson were also generally rural in nature, with narrow lane widths and an absence of pedestrian facilities. In this situation, automobile traffic volume and traffic speed most influenced pedestrian level of service. For example, Figure 6.7 is a picture of Elm Street in the city of Clemson, a representative sample of a typical local street within the study area. This road was ranked as a pedestrian level of service D. As evident in the picture, this road was used by pedestrians, but was less than ideal. Two large apartment complexes were located on Elm Street, generating a large amount of automobile traffic that, combined with the narrow traffic lanes and absence of pedestrian infrastructure, provided little comfort to pedestrians. Pedestrians often resorted to walking in the ditch, especially during periods of high traffic or low light. This situation likely resulted in only people with no other transportation options walking on the road. Hence, the pedestrian level-of-service ranking of D, which can be interpreted to mean it is possible but not desirable to travel this road segment by foot, and people with another travel option will choose not to walk.

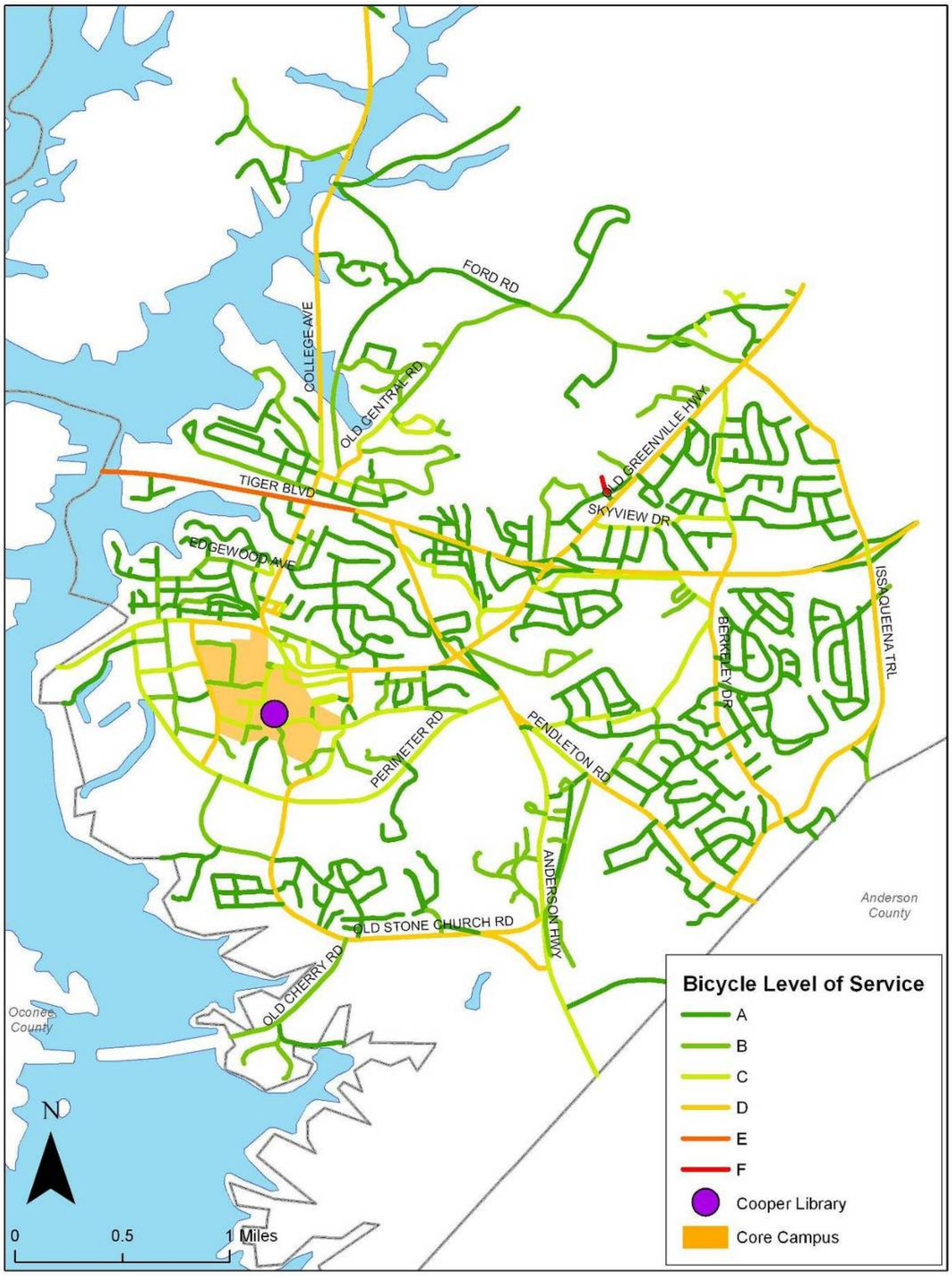
Figure 6.7 – Elm Street, City of Clemson



The bicycle level of service (Figure 6.8) also made sense intuitively. Bicyclists generally favor low-speed, low-traffic volume roads, and the local roads in the study area scored a correspondingly high level of service for bicyclists. On the other hand, and opposite from the pedestrian network, some of the important access roads to the core campus did not score as suitable for bicyclists.

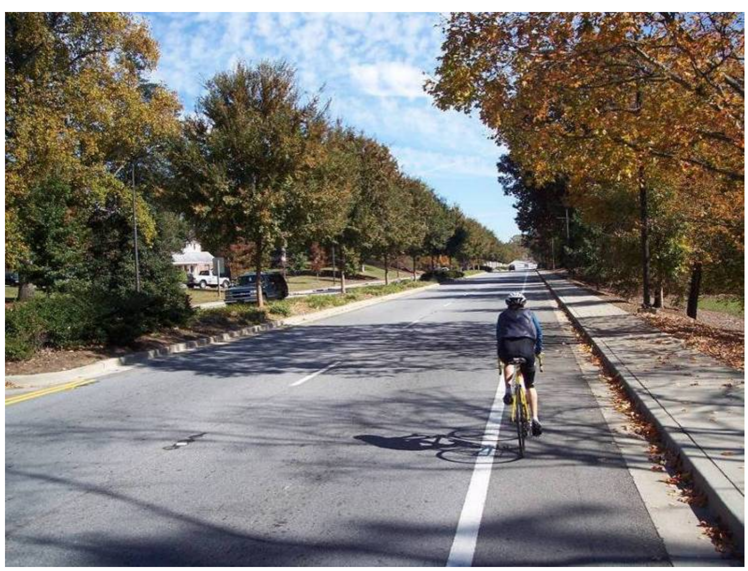
College Avenue, in particular, scored as level of service D, which would consequently constrain the bicycle commute catchments significantly to the north as this road was the most direct route in that direction. College Avenue scored low, as unlike for pedestrians, the road segments did not provide dedicated bicycling infrastructure in a relatively-high automobile volume corridor.

Figure 6.8 – Bicycle Level of Service



While College Avenue was expected to be assigned a low level of service for bicyclists, a surprising ranking emerged for portions of Old Greenville Highway. Segments of Old Greenville Highway beginning just east of the core campus and heading across Tiger Boulevard were assigned a bicycle level of service of D. These road segments were recently reconstructed with dedicated, four-foot bike lanes on both sides of the highway as evident in Figure 6.9. However, the relatively-high automobile traffic volumes and high speed limit of 40 miles per hour for this segment were responsible for the relatively-low score. While this score did surprise the researcher, it did provide an explanation for a curious observation. Viewing bicyclist behavior on this road segment has shown that most cyclists appeared more comfortable riding on the sidewalk adjacent to the road, despite the availability of dedicated signed bike lanes. Generally, only experienced recreational cyclists appeared comfortable using the bike lanes on Old Greenville Highway. These informal observations by the researcher lent anecdotal support to the low level of service ranking of the model.

Figure 6.9 – Old Greenville Highway, City of Clemson



WALKING AND BICYCLING COMMUTING CATCHMENTS

Now that the 75th-percentile maximum acceptable distances and the level of service of road segments had been calculated for pedestrian and bicycle commuting, the commuting catchments were identified by combining these two outputs. Specifically, the commuting catchments were identified by calculating the maximum acceptable commute distances for walking and bicycling along road segments that scored a level of service C or better. The results are illustrated in Figure 6.11 and 6.12.

As is evident in both Figure 6.10 and 6.11, the actual commute catchments for walking and bicycling to Clemson University were significantly constrained by the suitability of the transportation network. Pedestrian commuting was already significantly constrained by the slow speed of pedestrian travel, but the less direct paths pedestrians would have to take to travel on acceptable level-of-service road segments lessened the actual commute catchment even further. The bicycle commute catchment was even further constrained. If all road segments were at an acceptable level of service for bicycle commuting, virtually the entire city of Clemson would be within bicycle commuting distance of campus. However, due to the poor level of service provided to bicyclists on some of the main commuting corridors accessing the core campus of Clemson University, bicycle commuting was generally constrained to the neighborhoods immediately north and south of Clemson University.

Figure 6.10 – Walking Commute Catchment

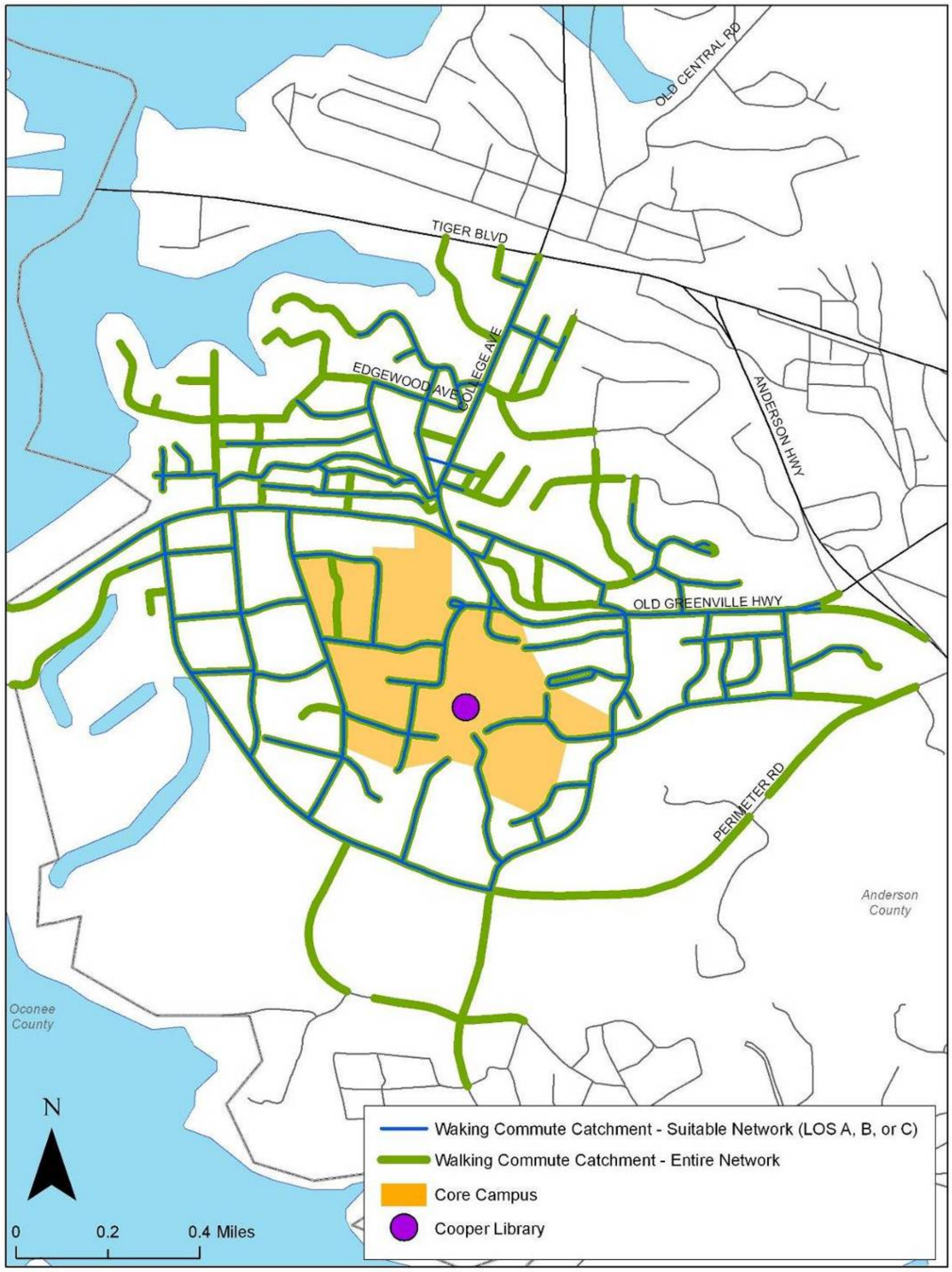
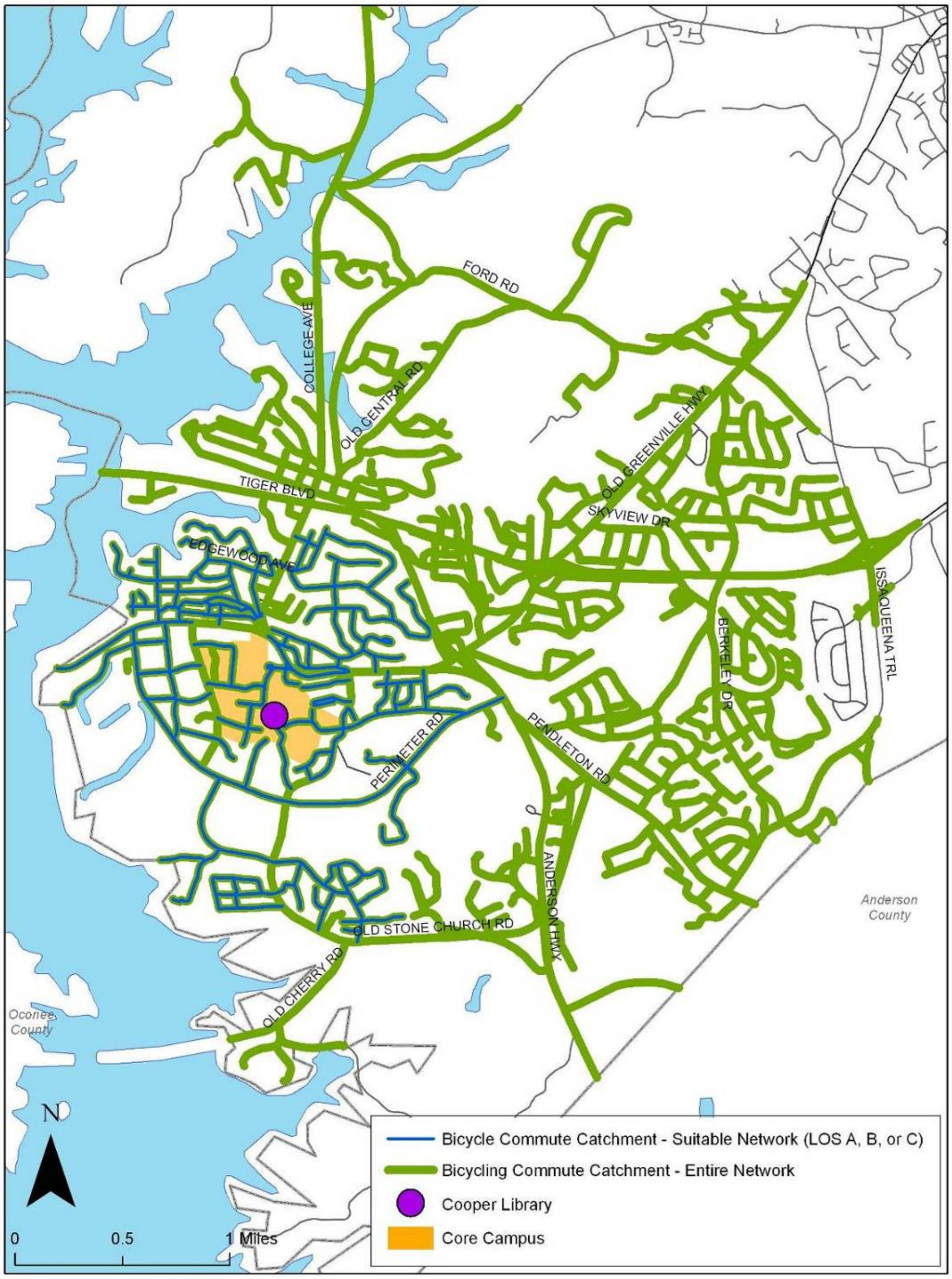


Figure 6.11 – Bicycling Commute Catchment



To put these commuting catchments in a land use access perspective, Figures 6.12 and 6.13 illustrated the parcels within the city of Clemson that were accessible from the core campus of Clemson University by walking and bicycling. The parcels were identified by selecting those that were within 100 feet of a road segment that was either within the commute catchments of Figures 6.10 and 6.11, the maximum network distance, or outside of the maximum commuting range. Blue represents accessible parcels that people should be expected to commute from under present conditions, green represents the parcels that people could commute from if the infrastructure was improved enough to provide a level of service C or better, and brown represents parcels that would be outside of the mode's commuting range for most people regardless of the level of service, excluding any transportation network construction that might shorten the network distance to the core campus.

Figure 6.12 – Parcels Accessible by Pedestrian Commuting

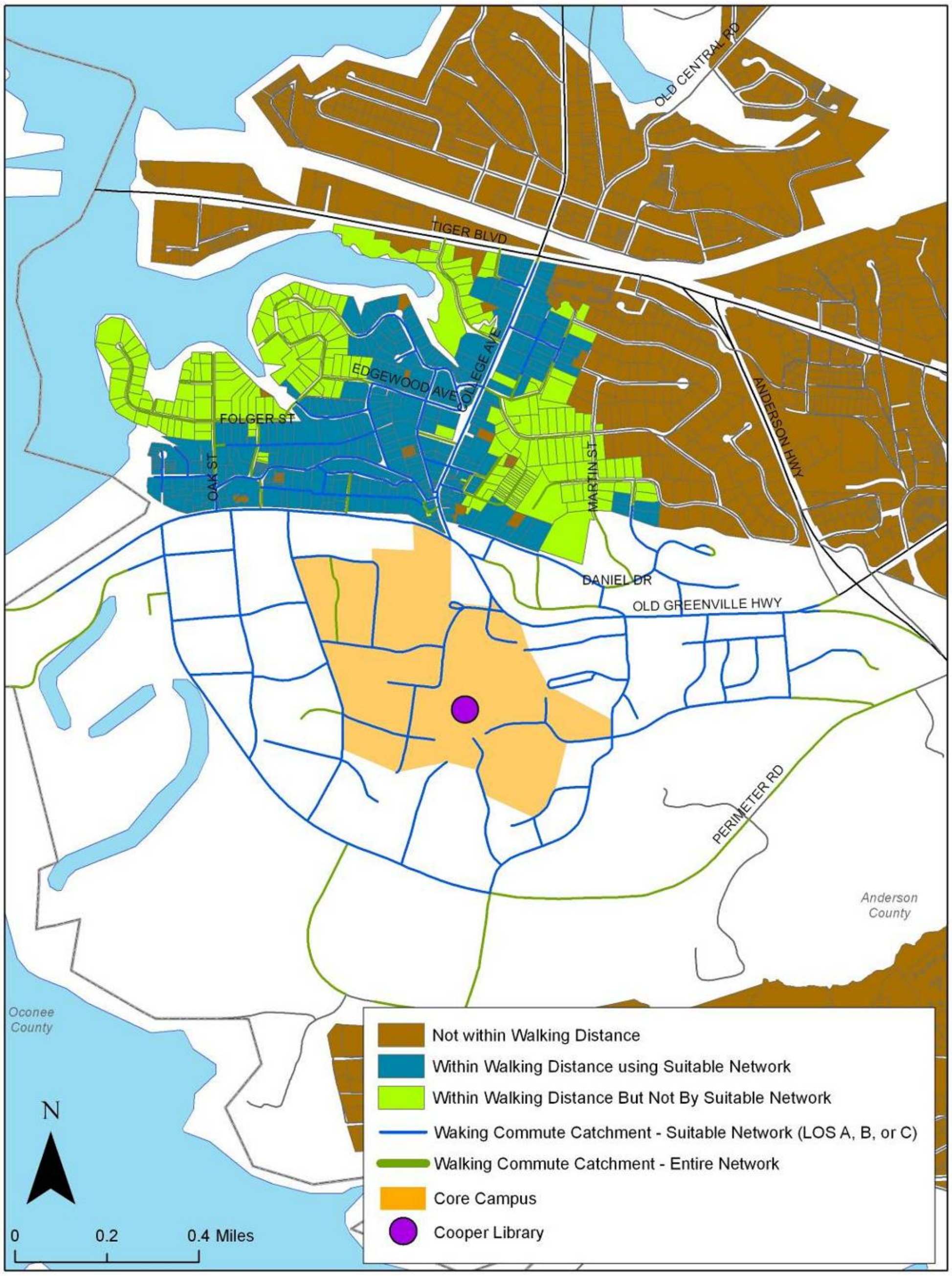
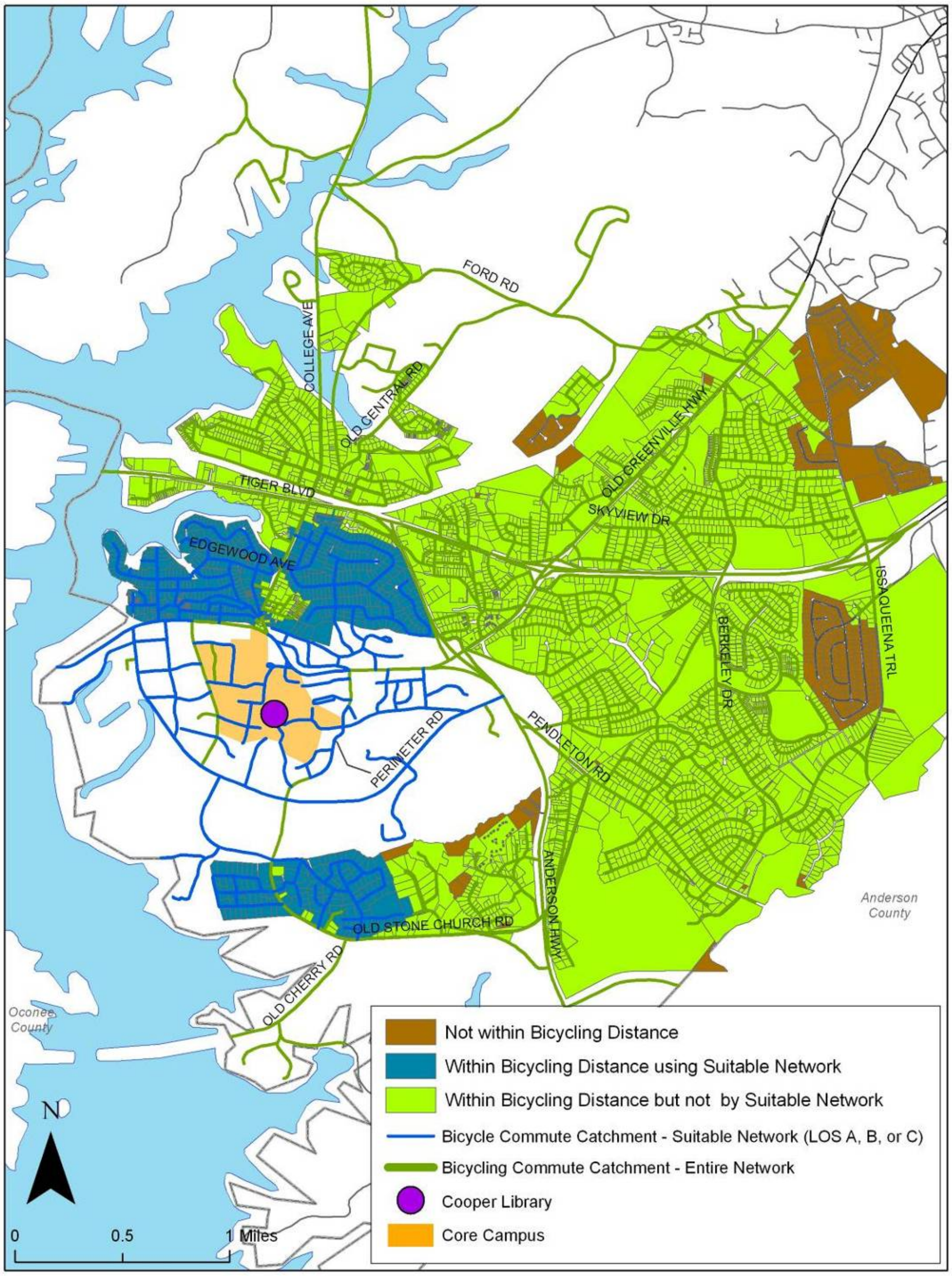


Figure 6.13 – Parcels Accessible by Bicycle Commuting



Due to the nature of land use within the study area and the location of Clemson's core campus in respect to Clemson University land as a whole, the only off-campus property that had the potential to generate substantial pedestrian commuting appeared in the green and blue areas of Figure 6.12. A significant amount of that area was already accessible, but poor levels of service on Oak Street, Edgewood Avenue, Folger Street, Martin Street, and Daniel Drive prevented a number of parcels that were within walking distance from falling within the current actual pedestrian commute catchment.

The potential to increase the number of parcels accessible by bicycle commuting was much larger due to the much larger maximum acceptable commute distance of bicycling. However, the unsuitable segments of College Avenue, Old Stone Church Road, Old Greenville Highway substantially decreased the area from which people could commute by bicycle to Clemson University. However, infrastructure improvements on arterial road segments could be expensive, especially in the case of a road like Old Greenville Highway, where four-foot bike lanes still have not provided an acceptable level of service due to high vehicle traffic volumes. Improving the level of service on the important arterials that provide access to Clemson University might require transportation demand management strategies such as reduced speed limits or disincentives to reduce automobile volumes in order to make the roads acceptable for commuting by bicycle for the majority of campus commuters.

CAMPUS MEMBER COMMUTING POSSIBILITIES

Year 2005 Clemson University faculty, staff, and off-campus student address information was then geocoded to develop a spatial distribution of campus member residence locations respective of the walking and bicycling commute catchments. Due to the nature of the address information, an influential assumption had to be made. Clemson University did not require students to report a local address, and consequently, many of the addresses that Clemson University had for students was actually the students' more permanent addresses, such as their parents' or guardians' residences. However, some students might actually be commuting from a parent's house that was 40 miles away in Greenville, South Carolina while other students who had a permanent address in Greenville might have moved closer to Clemson University either to reduce their commute distance or simply to experience "student living." Because of this uncertainty, a 20-mile radius of Clemson University was used as a cut-off to identify local off-campus student addresses as compared to permanent addresses that students were not actually commuting from on a daily basis. It is important to remember that the off-campus student address data and subsequent commute catchment calculations suffer from the limitation of this assumption. Faculty and staff address information was assumed to be more permanent and accurate, and the local radius was not used as a cut-off for their addresses. In addition, on-campus students were not included in this analysis, and the 6,175 on-campus student residents in 2005 were assumed to have the ability to walk or bicycle to campus.

The actual count and distribution of campus community resident addresses among the walking and bicycling commute catchments represented a sample of the total campus population, and are represented in Tables 6.6 and 6.7. Table 6.6 details the distribution of campus member residences among the actual and theoretical walking commute catchments, and Table 6.7 details the distribution of campus member residences among the actual and theoretical bicycle commute catchments. These counts were extrapolated out to represent the full faculty, staff, and off-campus student population of campus, and thus Tables 6.8 and 6.9 represent the estimated number of Clemson University commuters who had (actual catchments) or potentially could have (theoretical catchments) the option of walking or bicycling to Clemson University.

As is evident in Table 6.8, only 4 percent, or 673 off-campus commuters, lived within the actual commute catchment for walking, and thus could walk to school. The unsuitable road segments prevented another 2 percent, or 188 campus members, from having the option to commute by walking. Nevertheless, 94 percent of campus commuters (not including on-campus student residents) lived outside of an acceptable walking distance. Faculty and students were more likely to live within walking distance of campus, perhaps reflecting their increasing desire for proximity due to the more “hectic” nature of their schedules, whereas staff were more likely to be commute to campus less frequently.

As is evident in Table 6.9, a slightly greater number of campus commuters had the option of bicycle commuting: 7 percent or 1,117 commuters. Unsuitable road segments within the city of Clemson prevented a significantly greater number of commuters from having the option of commuting by bicycling: 28 percent, or 4,234 campus commuters lived within an acceptable bicycle commute distance but were prevented from bicycling by the deficiency of the transportation network.

These counts needed further refinement in order to compare the inferred mode split of campus commuters from this methodology to the Clemson Travel Pattern's mode split as given by survey respondents. People residing within both the walking and bicycling commute catchments could not be double-counted; therefore, they were assumed to walk and were thus removed from the count of people who could bicycle commute. Additionally, it is important to recognize that some campus commuters would never commute by walking or bicycling as detailed in Tables 6.3 and 6.4 Thus, the percentage of campus members who said they would never walk or bicycle to commute must be removed from the total number of campus members residing within the actual walking and bicycling commute catchments to develop a more accurate forecast of how many of these campus members would commute by walking or bicycling.

Table 6.6 – Commuters by Walking Potential

	Faculty		Staff		Off-Campus Students		Total Off-Campus Commuters	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Within Actual Commute Catchment	45	4%	18	1%	177	5%	240	4%
Within Theoretical Commute Catchment	66	5%	29	1%	221	7%	316	5%
Local Addresses	1,235	100%	2,041	100%	3,249	100%	6,525	100%

Table 6.7 – Commuters by Bicycling Potential

	Faculty		Staff		Off-Campus Students		Total Off-Campus Commuters	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Within Actual Commute Catchment	142	11%	49	2%	264	8%	455	7%
Within Theoretical Commute Catchment	396	32%	284	14%	1,334	41%	2,014	31%
Local Addresses	1,235	100%	2,041	100%	3,249	100%	6,525	100%

Table 6.8 – Commuters by Walking - Extrapolated

	Faculty		Staff		Off-Campus Students		Total Off-Campus Commuters	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Within Actual Commute Catchment	48	4%	26	1%	599	5%	673	4%
Within Theoretical Commute Catchment	71	5%	42	1%	748	7%	861	6%
Actual Total	1,322	100%	2,980	100%	10,990	100%	15,292	100%

Table 6.9 – Commuters by Bicycling - Extrapolated

	Faculty		Staff		Off-Campus Students		Total Off-Campus Commuters	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Within Actual Commute Catchment	152	11%	72	2%	893	8%	1,117	7%
Within Theoretical Commute Catchment	424	32%	415	14%	4,512	41%	5,351	35%
Actual Total	1,322	100%	2,980	100%	10,990	100%	15,292	100%

Table 6.10 reflects the extrapolated and adjusted estimate of the total number of campus members who resided within the walking and bicycling commute catchments. These data reflect the total number of people who should actually be walking or bicycling to the core campus of Clemson University. For comparison purposes, Table 6.11 is the extrapolated count of the mode split for off-campus Clemson University commuters calculated from the 2005 Clemson Travel Patterns survey. As is evident, the number of commuters and mode split of the survey is very similar to the calculated number of commuters who should be expected to currently commute by walking and bicycling, giving credence to the accuracy of the commute catchments.

Table 6.10 – Commuters by Expected Mode Split

	Total Off-Campus Commuters	
	Extrapolated Count	Percent
Walking - Adjusted	633	4%
Bicycling - Adusted	314	2%
Total Commuters	15,292	100%

Table 6.11 – Commuters by Mode Split – 2005 Survey

	Total Off-Campus Commuters	
	Extrapolated Count	Percent
Walking	691	5%
Bicycling	348	2%
Public Transit	846	6%
Automobile	13,342	87%
Other	65	0%
Total Commuters	15,292	100%

The same adjustment for commuters unwilling to commute by walking or bicycling was used to explore the expected mode split for pedestrian and bicycle commuting if the entire network within the theoretical walking and bicycling commute catchments was suitable for travel by these modes, and is detailed in Table 6.12.

Table 6.12 – Commuters by Potential Mode Split

	Total Off-Campus Commuters		
	Extrapolated Count	Percent	Commuters Gained
Walking - Adjusted	809	5%	177
Bicycling - Adjusted	2,829	18%	2,515
Total Commuters	15,292	100%	0

As can be seen in Table 6.12, improving the unsuitable network segments within the city of Clemson that have presented barriers to non-motorized modes of commuting to Clemson University could cause a substantial mode shift. Pedestrian commuting could consist of 5 percent of the commute trips to Clemson University, while bicycling could serve 18 percent of the commute trips to Clemson University, assuming that the entire transportation network within the walking and bicycling commute catchments was made suitable for pedestrian and bicycle travel and that Clemson University campus members commuted by walking and bicycling up to the acceptable times they stated they would in the 2005 Clemson Travel Patterns survey. It is important to remember that these forecasted mode splits have not assumed any change in land use near Clemson University towards higher density housing, which could have an even larger effect on mode split.

CATCHMENT LAND USE POLICY CHARACTERISTICS

It is important to consider the underlying land-use characteristics and local planning policies that affect the land use within the identified commuting catchments. To explore this concept, the generalized future land use plan of the City of Clemson was used to calculate and identify the types and relative distributions of different land uses within the commuting catchments. The future land use was used instead of current land use due to the incomplete availability of existing land-use data within the city of Clemson. However, the city of Clemson is generally fully developed, and it is fair to say that the City of Clemson's Future Land Use policy generally represented existing land use characteristics. Furthermore, analyzing the City of Clemson's "Future Land Use" policy allowed a comparison between the City of Clemson's local government policy and its relation to Clemson University's policy of sustainable commuting patterns. Tables 6.13 and 6.14 depict the distribution of future land uses in the pedestrian and bicycling catchments, respectively.

Table 6.13 - Land Use by Pedestrian Accessibility

	Within Walking Catchment		Within Walking Distance		Within Entire City of Clemson	
Future Land Use	Acres	%	Acres	%	Acres	%
High Density Residential	20	14%	38	15%	299	9%
Medium Density Residential	7	5%	8	3%	810	24%
Low Density Residential	55	41%	152	59%	1,770	52%
Mixed Use	7	5%	11	4%	29	1%
Commercial	44	32%	47	18%	254	8%
Public/Institutional/Utilities	0	0%	0	0%	153	5%
Parks/Recreation	3	2%	3	1%	58	2%
Other	0	0%	0	0%	14	0%
Total	135	100%	257	100%	3,388	100%

Table 6.14 - Land Use by Bicycling Accessibility

Future Land Use	Within Bicycling Catchment		Within Bicycling Distance		Within Entire City of Clemson	
	Acres	%	Acres	%	Acres	%
High Density Residential	33	7%	260	9%	299	9%
Medium Density Residential	8	2%	735	24%	810	24%
Low Density Residential	369	83%	1,565	52%	1,770	52%
Mixed Use	7	2%	29	1%	29	1%
Commercial	24	5%	253	8%	254	8%
Public/Institutional/Utilities	0	0%	130	4%	153	5%
Parks/Recreation	3	1%	54	2%	58	2%
Other	0	0%	8	0%	14	0%
Total	443	100%	3,034	100%	3,388	100%

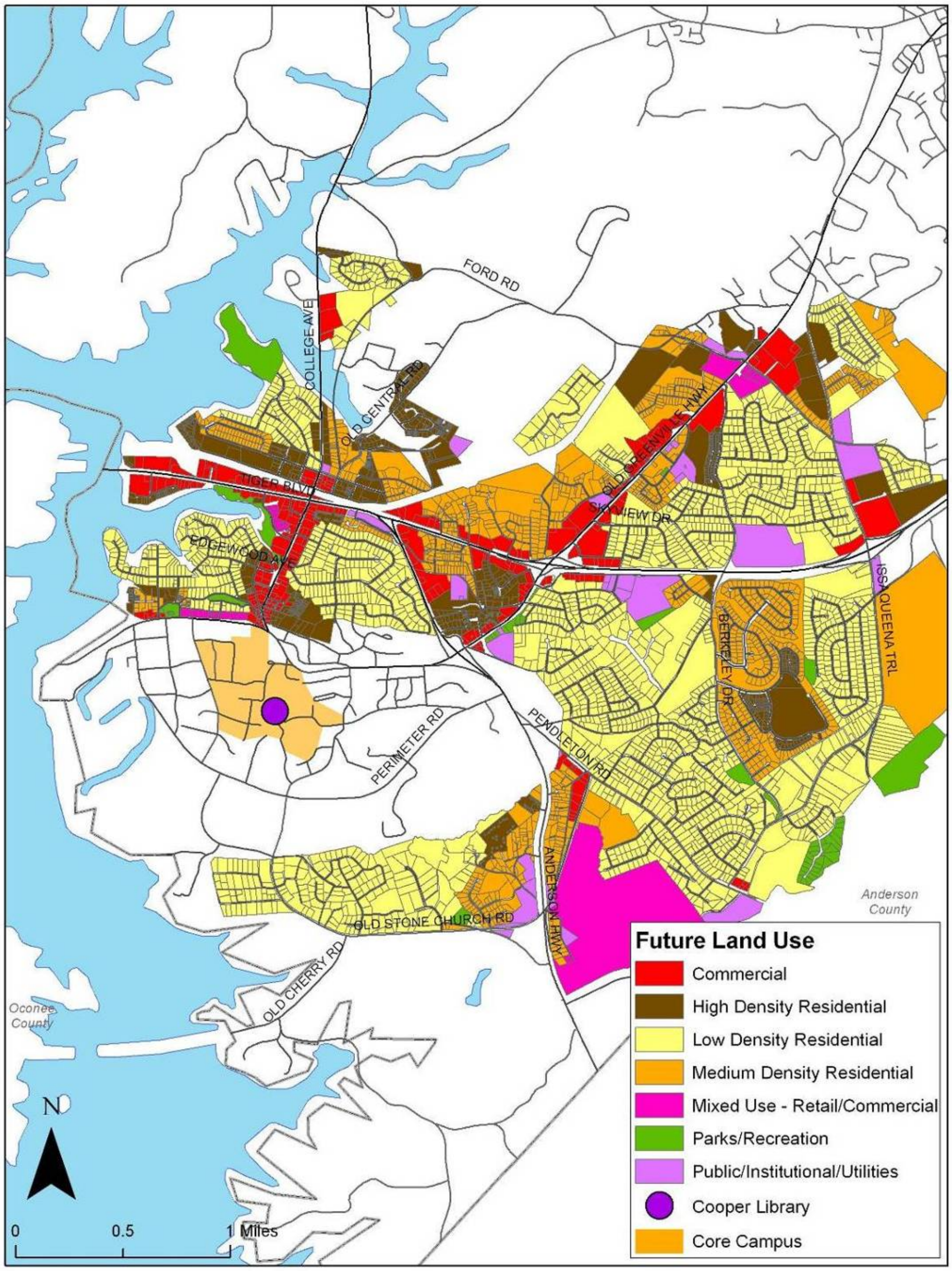
As the tables show, low-density residential housing was the largest land use in terms of acreage planned for the area within both the pedestrian and bicycle commute catchments. Of the acreage within the city of Clemson is currently accessible to the core campus by pedestrian commuting, 41 percent was planned for low-density residential housing. Likewise, 59 percent of the entire acreage that lay within walking distance of the core campus was planned for low-density residential housing. A similar pattern was shown within the bicycling commute catchment.

Medium-and high-density residential housing, which was planned for 33 percent of the total acreage of the city of Clemson, made up only 19 percent of the area currently accessible by pedestrian commuting, and only 18 percent of the area within walking distance of the core campus of Clemson University. This difference between the relatively high percentage of medium-to high-density residential housing within the entire city of Clemson and relatively low percentage actually planned within walking distance worked against the goal of encouraging more sustainable commuting patterns to Clemson University by providing an overall low number of people with the option of living within an acceptable non-motorized commute distance of the core campus.

While low-density residential housing should be expected to make up a large percentage of a typical city's land area, what is unique about this situation is the predominance of low-density residential housing within proximity to Clemson University. In a university setting, one might expect a predominance of higher-density residential land use catering towards off-campus students to locate along the periphery of the campus, while lower-density single family housing might generally reside further away from the traffic, noise, and other externalities that a large university generates.

Figure 6.14 (next page) is an illustration of the City of Clemson's generalized future land use, and the predominance of low-density residential housing (yellow) within proximity to Clemson University is illustrated. Conversely, a large percentage of the area planned for medium-to high-density residential use is located on the north side of Tiger Boulevard, outside of the potential walking commute catchment.

Figure 6.14 – Future Land Use, City of Clemson



RESULTS FOR CLEMSON UNIVERSITY

Presently, Clemson University's heavy reliance on automobiles for commuting to campus works against the goal of greater sustainability. If the university is truly interested in addressing sustainability, as well as reducing the amount of land needed for parking and moderating the externalities created by the large amount of campus commuters, it will have to take steps to both discourage automobile commuting and encourage commuting by walking and bicycling.

As the actual pedestrian and bicycle commute catchments showed, the geographic area from which campus commuters have had the option of commuting by walking or bicycling has been constrained by the unsuitability of the transportation network. This effect is more pronounced for bicycling than for walking due to the relatively larger network distance from which a person would be willing to commute by bicycle. Nevertheless, if the unsuitable road segments within the theoretical walking and bicycling commute catchments were made suitable for walking and bicycling, an additional 177 campus members would be predicted to commute by walking while an additional 2,515 commuters could commute by bicycle. Without even considering the positive externalities created by a reduced number of automobile commuters, the costs associated with providing automobile parking structures for 2,692 commuters on campus would be approximately $26.9 million annually. This large sum of money could instead be put toward the construction of walking and bicycling facilities within the city of Clemson and consequently enable a shift towards more sustainable commuting patterns. Of course, an agreement between the city of Clemson and Clemson University would have to be undertaken to coordinate using university funds on city-owned infrastructure. The specific implications and recommendations for walking and bicycling are addressed separately below.

WALKING

Pedestrian commuting to Clemson University will be constrained to a relatively small geographic area regardless of network suitability due to the slow commuting speed and consequently small commuting distance commuters are willing to walk. Even if the entire transportation network in the study area was suitable for walking, pedestrian commuters could only be expected to originate from the area immediately north of Clemson University and South of Tiger Boulevard as was illustrated in Figure 6.12.

Due to the small distance from which pedestrians are willing to commute, the network connectivity, pedestrian suitability, and land use adjacent to Clemson University's core campus are the most important factors in determining the amount of Clemson commuters who have the option of commuting as a pedestrian. As an informal observation, network connectivity within the potential pedestrian commute catchment is fairly good, with relatively few unconnected streets or cul-de-sacs. Furthermore, the network distance analysis in this research did not take into consideration informal, pedestrian-only cut-throughs that could have the effect of considerably shortening some network distances through improved pedestrian connectivity.

Pedestrian suitability is likewise fairly good within the potential pedestrian commute catchment. Importantly, most of the main transportation corridors connecting Clemson University with the surrounding area were found to be suitable for pedestrian use. Clemson Avenue and Tiger Boulevard both scored a Level of Service C, and the dedicated sidewalk infrastructure along these roads plays an important role in providing pedestrian connectivity to the core campus. The easternmost section of Perimeter Road and Old Stone Church Road stand out as the most unsuitable road for pedestrians, but the poor pedestrian suitability of these two roads should not be as big of a concern. This is because the land use characteristics of the area south of Clemson University place very few houses within walking distance of the campus using these two corridors anyway.

While most of the arterial roads providing access to Clemson University were found to provide an acceptable level of pedestrian suitability, a few local roads within proximity to the core campus were found to be barriers to pedestrian commuting due to higher traffic volumes and a lack of dedicated pedestrian infrastructure as discussed earlier. These road segments include: Oak Street, Edgewood Avenue, Folger Street, Martin Street, and Daniel Drive. Installing four foot sidewalks on these unsuitable road segments would improve their levels of service to a score of B and extend the actual pedestrian commute catchment significantly to include the remaining parcels that are within walking distance of the core campus of Clemson University.

However, since the potential pedestrian commute catchment will remain relatively small in geographic terms, the most influential factor in enabling greater pedestrian commuting is the density of housing within the potential commute catchment. The land use analysis showed that the parcels within the City of Clemson that lie within walking distance of Clemson University are best characterized as low-density, single-family housing. The low-density housing characteristics of the neighborhoods surrounding Clemson University certainly limits the number of Clemson University members who can choose to live within walking distance of campus.

The City of Clemson's current land use patterns and future land use plans conflict with the goal of encouraging greater pedestrian commuting to Clemson University. The City of Clemson's zoning generally allows low-density, single family housing within the neighborhoods closest to Clemson University, while encouraging higher-density student housing to be built further away from the campus. This explicit land use policy, as evident in Figure 6.14, has the effect of limiting the potential number of campus commuters who might choose to live within walking distance based simply on the resulting population density of the different land uses. Furthermore, the City of Clemson has allowed and perhaps even encouraged the construction of high-end condominiums within the pedestrian commute catchment that are marketed toward part-time, non-Clemson University commuters who would primarily use the condos during sporting events. This type of part-time, non-student oriented developments within the pedestrian commute catchment will only serve as a barrier to increasing the number of campus commuters who could commute by walking.

If the City of Clemson and Clemson University where truly interested in encouraging greater pedestrian commuting, encouraging a shift to higher-density housing within the potential pedestrian commuting catchment would be the most influential policy decision that could be implemented. Simply put, the more people who are able to live within walking distance of the core campus, the more people will walk.

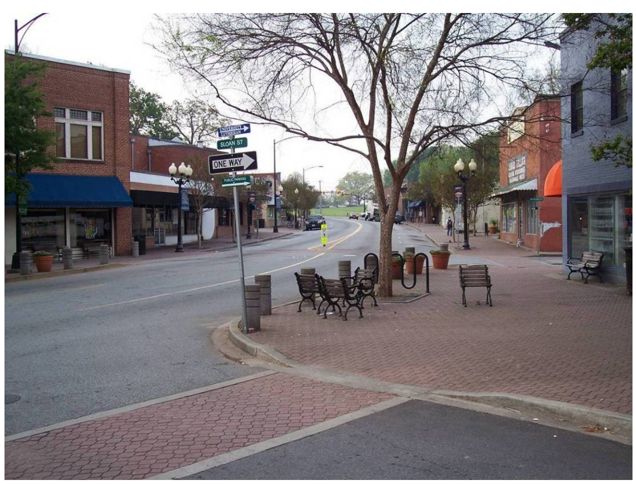
BICYCLING

Bicycle commuting showed a much greater potential commute catchment based on the stated, maximum acceptable commute times of Clemson University members and the relatively higher commuting speed of a bicyclist compared to a pedestrian. However, the actual catchment for bicycling commuting to Clemson University is significantly reduced to an area only slightly larger than the pedestrian commuting catchment.

Unlike the pedestrian level of service, most of the major arterial roadways providing access to Clemson University were found to be unsuitable for most bicyclists. In particular, the unsuitable nature of Clemson Avenue and Old Greenville Highway significantly constrain the area from which a person is able to commute by bicycle to Clemson University. The generally unsuitable nature of these arterial roadways for bicyclists as compared to pedestrians reflects the important role that automobile traffic volume and traffic speed have on influencing a bicyclists perceived comfort on a roadway. While pedestrians are provided dedicated infrastructure that isolates themselves from automobile traffic, bicyclists are expected to share the same roadway as automobile traffic. Even when dedicated bicycle lanes are present, as in the case of portions of Old Greenville Highway, higher automobile traffic volumes and traffic speeds can override the comfort that these non-grade, non-buffered dedicated bicycle lanes may provide.

Improving these unsuitable arterial roadways to a level of service of C for bicyclists may prove challenging in two ways. Attempting to address a lack or deficiency in bicycling infrastructure could be prohibitively costly or impractical, such as in the case of Old Greenville Highway or College Avenue. Both of these arterial roadways possess right-of-way width challenges that would only allow bicycling infrastructure to be installed or widened by either narrowing the existing pedestrian infrastructure or automobile traffic lanes. Figure 7.1 illustrates the right-of-way challenges of College Avenue in downtown Clemson that makes the construction of dedicated bicycle lanes impractical in the short term.

Figure 7.1 – College Avenue, Downtown Clemson



The second method that could improve bicycle level of service on the arterial roads is less cost extensive but perhaps more politically challenging: transportation demand management strategies. Specifically, strategies to reduce automobile traffic volume, traffic speed, or both have the potential to significantly improve the level of service of roads such as College Avenue and Old Greenville Highway. For example, lowering the 40 miles per hour speed limit to 25 miles per hour on the portion of Old Greenville Highway with four foot bike lanes that is currently rated as a level of service “D” would improve the level of service to a “C”. Additionally, the university could lower automobile traffic volumes through measures aimed at reducing automobile commuting, such as raising the cost of parking or providing incentives for non-automobile commuting.

Unfortunately, implementing strategies that are intended to improve network suitability and bicycle commute access to Clemson University by negatively impacting automobile travel will tend to be politically difficult. This scenario creates a dilemma: Is it appropriate to use disincentives that impact the entire automobile commuting population in order to increase bicycle commuting options for those who live within bicycling distance of the campus? Considering that 37 percent of campus members are never willing to commute by bicycle, the negative impacts to automobile commuters may be greater than the benefit of enabling greater bicycle commuting.

Regardless of this dilemma, the results of this study highlighted a number of unsuitable road segments for pedestrians and bicyclists that act as considerable barriers to increased non-motorized commuting to Clemson University’s core campus. According to the analysis of commuter housing location within the actual and theoretical commute catchments for walking and bicycling indicated that a substantial mode shift could be affected among campus commuters if the unsuitable road segments within walking and bicycling distance were improved to a better level of service. These improvements could allow over 2,500 additional campus commuters to commute by walking or bicycling, and has vast implications on whether university funding would be better spent on structured parking or non-motorized infrastructure in order to foster the goal of a sustainable campus.

CONCLUSION

This study used a unique combination of stated, acceptable maximum commute times and inferred network travel distances for walking and bicycling, combined with an assessment of the suitability of the transportation network for these modes to develop the walking and bicycling commute catchments from which a person should be reasonably expected to commute to a destination by walking or bicycling. This research built upon existing non-motorized level-of-service models that predict the transportation network's suitability for pedestrian and bicycle commuting.

This approach was demonstrated successfully for commuting to the core campus of Clemson University, but could be equally well suited to identifying the commuting catchments to any other major employer or downtown business district. The model's close calibration to the reported mode split to Clemson University indicates the validity of this approach for determining non-motorized commuting catchments to a major trip attractor. By using this model, transportation planners have a new tool for addressing the desire for a more sustainable transportation system. The results inform policy makers in terms of identifying unsuitable road segments that serve as major barriers to non-motorized forms of commuting, and also in terms of understanding appropriate land use policies for areas that have the potential to generate a large amount of walking or bicycling commuting.

Unfortunately, this research has illustrated the very limited area from which commuters should be expected to walk or bicycle to a campus based on the network distance campus members are willing to commute and the suitability of the transportation network for traveling by these modes. The geographic area from which pedestrian commuting can take place was and always will be constrained due to the relatively slow speed of pedestrians. However, unsuitable road segments can prevent the actual pedestrian commuting catchments from extending to their full potential.

Bicycle commuting showed a much greater potential catchments due to the relatively high commuting speed of a bicycle. However, bicycle commuting can be severely constrained when cyclists are forced onto busy arterial highways that exhibit a hostile environment and undesirable conditions for bicycle commuting. The unsuitable arterial road segments that constrained bicycle commuting in the study area point to the necessity of well-designed, dedicated bicycling infrastructure. This infrastructure is especially critical when a lack of connectivity leads to a lack of route choices for bicyclists, forcing them onto the same major arterials that serve automobile commuters. Alternatively, bicycle commuting could be improved through better network connectivity by providing multiple route options for bicyclists so they can avoid the most highly traveled roadways.

When relatively small commuting catchments are combined with low-density land use characteristics, the total number of commuters who have the ability to travel by walking and bicycling will in all likelihood be very small.

Herein lays a policy dilemma that many universities and municipalities may face. If a municipality or university implemented demand management measures to encourage a mode shift away from automobile commuting towards walking or bicycling, only a small percentage of the affected commuting population would currently have the option to switch modes.

Unfortunately, without disincentives to automobile commuting in place, there may be a perceived lack of need, lack of real lack of political will, and a lack in market forces to demand changes that would increase the number of campus commuters who could commute by walking or bicycling. For example, if more people were encourage to commute by walking, there may be increased competition and therefore higher market rates for housing within walking distance of large employment centers. The housing market may then respond by building higher-density housing within walking distance of campus. An increased number of people living within walking distance may then put greater demand on local decision makers to install dedicated pedestrian infrastructure on unsuitable roadways. In the long-term, market demand for land-use change will have the largest effect on facilitating walking and bicycle commuting.

In the short-term, addressing unsuitable road segments through the installation of dedicated pedestrian or bicycle infrastructure, or by reducing the speed of automobile traffic could substantially increase the geographic area from which people could commute by walking or bicycling. Improving the level of service of arterial roads may require policy makers to make a tradeoff between facilitating large amounts of high-speed automobile traffic or encouraging a sustainable transportation system that encourages travel by walking and bicycling. If decision makers wish to back up their wishes for a sustainable community, the choice is obvious but no less politically difficult.

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